ENGINEERING DOCTORATE

Warwick Manufacturing Group

University of Warwick

EXECUTIVE SUMMARY

A framework for the development of the polymer recycling system in the UK to achieve compliance with the European Directive on End of Life Vehicles

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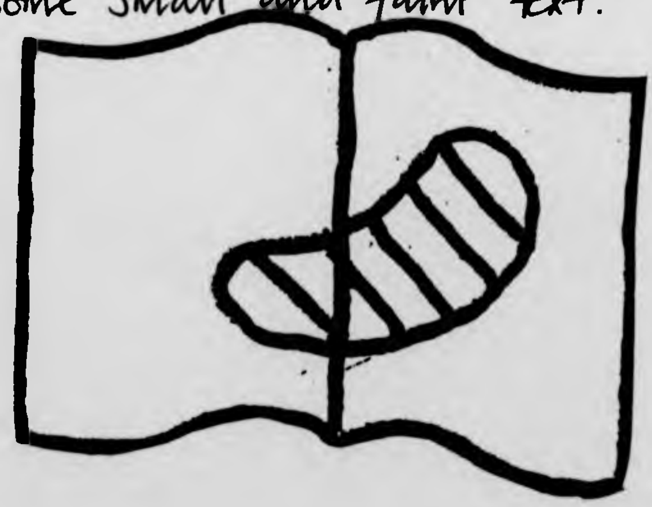

CONTENTS LIST

INDEX OF FIGURES

Acknowledgements

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Declaration

I, Sue Robson, declare that all the work presented within this submission was undertaken personally, unless otherwise acknowledged within the text, and that none of the work has been previously submitted for any other academic qualification that has not been authorised by the University.

Abstract

Legislation will be introduced within the UK by 2004 as a result of a European drive to reduce waste levels arising from the disposal of end of life vehicles (ELVs). With the emergence of the European Directive (2000) on ELV disposal, targets for reduction of waste from ELVs have been set. These targets signify that a major change in non-metallic material recycling and in particular polymer recycling is necessary to meet the legislation. Increasing numbers of vehicle components are made from plastic, replacing metals due to enhanced properties such as light weight, formability and material properties (e.g. corrosion resistance, insulation properties, energy absorption etc.). Ultimately this means that more spent plastic material will require disposal, whilst legislation will limit the amount that can enter landfill sites. Therefore alternatives to landfill for plastic waste need to be found.

Ideally plastic waste would be reprocessed and a resulting market found. However, the UK polymer recycling infrastructure cannot cope with high quantities of spent plastics, and there is no organisation that is capable of developing the processes that will be necessary to meet legislation.

The author has investigated the current state of plastics recycling in the UK with emphasis on technical and business issues. Soft Systems Methodology (SSM) has been used for the first time in this field to develop the theme and create a series of recommendations that could improve the current situation. An innovative approach using Hoshin Kanri to develop the SSM recommendations resulted in the creation of a framework for deployment that the author named 'the Polymer Recycling Hub'. The Hub could help all parties affected by the impending legislation to create a polymer recycling infrastructure capable of recycling high levels of spent plastic arising from ELVs. Interest in the Polymer Recycling Hub is growing and the author has the backing of many industrial organisations for its implementation.

Glossary of terms

ACORD	Automotive Consortium on Recycling and Disposal
ASR	Automotive Shredder Residue
BPF	British Plastics Federation
CARE	Consortium for Automotive Recycling
CATWOE	Definitions that collectively form the conceptual model within SSM
DETR	Department of the Environment, Transport and Regions
DFD	Design For Dismantling
DFR	Design For Recycling
DTI	Department of Trade and Industry
ELV	End of Life Vehicle
EMR	European Metal Recycling
ENTRUST	Regulator of Environmental Bodies for Landfill Tax Regulations
EPSRC	Engineering and Physical Sciences Research Council
EU	European Union
IMECHE	Institute of Mechanical Engineers
MBO	Management By Objectives
MIRA	Motor Industry Research Association
RAPRA	Rubber and Plastics Research Agency
SMMT	Society of Motor Manufacturers and Traders
SSM	Soft Systems Methodology
WMG	Warwick Manufacturing Group
UK	United Kingdom

1 Introduction

This Engineering Doctorate Portfolio focuses on issues surrounding recycling of plastics. The Rover Group, from 1996 to 1999, inclusive, sponsored the author and so this research has an automotive bias.

1.1 Project Justification

The following sections explain the rationale behind this piece of research and in particular why the Polymer Recycling System needs to be investigated and improved. It will begin by giving details of the automotive industry's use of plastics and the disposal of this material when it reaches the end of its useful life.

1.1.1 The automotive industry and its waste

In 1996, Rover Group's Environmental Programmes Manager identified the need for research into disposal of waste in the automotive industry. It stemmed from the fact that approximately 1.5 million vehicles reach the end of their lives in the UK each year[1], of which on average, 75% of each vehicle (by weight) is currently recycled and the remaining 25% is placed in landfill sites across the nation. This 25% waste, equates to approximately 0.4 megatonnes of material[2], of which approximately 112,500 tonnes is plastic (these are based on 1999 figures).

In contrast, plastic usage by the automotive manufacturers is increasing, as car companies substitute materials such as metals with plastic in many of their components. This serves to increase fuel efficiency through: decreasing the weight of the vehicle, improving vehicle performance and specification, decreasing pollution from vehicles through emission control and improving safety aspects. Therefore the projected figure for plastic waste entering landfill sites in the UK from end of life vehicles (ELVs) for the year 2012 is 195,000 tonnes[3]. Current trends indicate that this increase is likely to continue[4].

1.1.2 European legislation

Throughout Europe sites that are suitable for landfill are becoming increasingly difficult to find and are expensive to use and maintain[5]. For this reason, in 1990, the European Parliament received a proposal from the commission that announced its intention to produce regulations to control the quantities of seven priority waste streams entering landfill sites. These 7 waste streams are packaging, end of life vehicles, electrical and electronics, tyres, batteries, building and medical products. The packaging legislation was passed in 1994 and the next waste stream to be targeted was end of life vehicles (ELVs). The first draft ELV directive was published in 1992 and, following a lengthy period of consultation and revision, the Directive came into force in the year 2000.

The directive gives disposal targets of ELV material through reuse, recycling and recovery, which are shown in Figure 1. These terms are described in chapter 3.

	REUSE AND RECYCLING	REUSE, RECYCLING AND RECOVERY
Current Disposal	75%	75%
Minimum Disposal for 2007 (% weight)	80%	85%
Minimum Disposal for 2015 (% weight)	85%	95%

Figure 1. Current and future levels of reuse, recycling and recovery for ELV material
Source: Directive of the European Parliament and the Council on end-of-life vehicles, PE-CONS 3627/00.

From Figure 1 it can be seen that by the year 2015, 95% of ELV material by weight will need to be removed from the wastestream destined for landfill. This could be carried out by reusing the existing car parts in the second hand car parts market, recycling the material or recovering the hydrocarbon content or the latent energy from the material.

There will be penalties for non-conformance to this directive, and each country is able to set its own penalty levels. It is not yet known what penalties the UK government will prescribe, as draft legislation has not yet been published. However, these are likely to be sufficient to motivate industry to remove waste material from ELVs before they enter the wastestream destined for landfill, otherwise industry is likely to simply pay the fines and the environmental intentions of the legislation will be lost.

The European Directive states that the responsibility for achieving legislation targets falls on the automotive 'economic operators' where the definition of economic operators means 'producers, distributors, collectors, motor vehicle insurance companies, dismantlers, shredders, recoverers, recyclers and other treatment operators of ELVs, including their components and materials'[6]. So the automotive industry has much to do in the next thirteen years if it is to meet legislation.

1.1.3 Automotive Recycling

Currently, vehicles that have reached the end of their lives are generally either taken to a dismantler or to a shredder[7], where the metallic content is removed and the rest of the vehicle is sent to landfill. As the metallic content of the vehicle is generally recognised to be about 73% of the vehicle weight, it is clear that the currently recycled portion of approximately 75% is largely metallic in content. The other 2% is of variable material content but usually results from the reuse of vehicle parts, and can sometimes include items such as battery casings (polypropylene plastic)[8].

Plastic is the second most widely used material in the vehicle manufacturing process - currently in the order of 12% (excluding elastomeric components such as tyres and door seals, or approximately 18% if they are included). Therefore, if all the metal and plastic were recycled, the target set for 2007 would be achieved with only a further 4% of material weight needing to be removed from the ELV to ensure legislative targets are met for 2015.

1.1.4 The Problem Defined

Information contained in sections 1.1.1, 1.1.2 and 1.1.3 gives information about the current situation of vehicle recycling and pending legislation relating to this. However the polymer recycling infrastructure is not sufficiently developed to cope with the quantities of material that will have to be reprocessed in to meet impending legal requirements. Nor has the demand for reprocessed plastic been established to the extent where all the waste plastic material coming from ELVs could be sold.

Thus it is clear that the infrastructure and demand for recycled plastics from ELVs need to be developed, in order to create systems capable of removing sufficient material to meet the targets set out in the 2000 European Directive.

1.1.5 Previous Research into UK Automotive Polymer Recycling

This field is a relatively new area of research and there have been limited previous investigations. Some projects have been carried out within various Universities, such as Nottingham[9], Brighton[10], Brunel[11] and Warwick[12]. Associations such as the Consortium of Automotive Recycling (the CARE group), British Plastics Federation (BPF), Society of Motor Manufacturers and Traders (SMMT) and Motor Industry Research Agency (MIRA) have also been active in this area, as have individual companies such as BMW, The Rover Group, Nissan, Toyota, ICI, BP, Ford Motor Company and Jaguar Cars Ltd[13]. However, a literature search has shown no holistic and comprehensive work that has been carried out to further change.

1.2 Main Themes of this research

1.2.1 Technical Aspects of Polymer recycling for the automotive industry

The author began research on the technical aspects of thermosetting polymer recycling, but later broadened the research to encompass recycling of thermoplastic, thermosetting, mixed plastic waste (MPW) and Automotive Shredder Residue (ASR).

After several months of research into the technical aspects of polymer recycling it became clear that there are many methods available for recycling plastics. However, the very limited extent of polymer recycling activity in UK at present led the author to discover that there are many other issues involved in polymer recycling and each has a contributory part to play in current low levels of polymer recycling of ELVs.

1.2.2 Business aspects of polymer recycling for the automotive industry

The next stage of research looked at the business aspects of polymer recycling for the automotive industry. This research gave the author a basic understanding of the draft directive (as it was then), the market for recycled plastics, including issues such as supply and demand, and the external market forces which affect the polymer recycling industry, financial, material pre-processing and transportation issues.

As research into the business aspects of polymer recycling progressed, it became clear that the people involved in the industry including design engineers, fellow researchers and industrial specialists had varying conceptions, beliefs and judgements associated with recycling plastics. This variety of beliefs seemed to create barriers to the recycling of plastics and the re-use of this material.

At this point the author decided, in agreement with her industrial mentor, to undertake a study to further understand polymer recycling and the implications of this to the automotive industry, ensuring that the views of people from the various sectors within and affected by automotive polymer recycling were taken into account. It was felt that until this was fully understood it would be very difficult to make any changes to the existing automotive recycling industry, or to develop a new system capable of reprocessing the high volume of polymeric waste from ELVs in the UK.

1.2.3 Research into problem solving techniques and methodologies suitable for addressing the Polymer Recycling System

The author investigated problem solving techniques and methodologies in order to find a problem solving system that was capable of analysing polymer recycling in the UK. The technique or methodology would need to be capable of dealing with complex and ill-defined issues, incorporating objective and subjective information. Furthermore, it would have to cope with the interwoven nature of the issues within the Polymer Recycling System and incorporate the associated human issues.

The most appropriate methodology for this investigation was found to be Soft Systems Methodology (SSM) and this was used to carry out an investigation of ELV polymer recycling in the UK.

1.2.4 An investigation into the Polymer Recycling System using SSM

SSM was used to carry out a detailed analysis of the Polymer Recycling System. Initially, individuals were invited to comment about what recycling of plastics meant to them. Responses came from a wide range of groups. These included: the public sector, school children, researchers, design engineers, moulders and experts in the field.

This information was collected and affinity diagrams were created from the information contained within. Several affinity diagrams were used to collectively create the overall ‘rich picture’ in SSM terms.

Four SSM analyses were then carried out focusing on the economic, government, technical and education sub-systems within the Polymer Recycling System. These analyses not only gave the author a greater understanding of the current Polymer Recycling System, they also showed what barriers would have to be addressed before attempting to change the current situation.

The resultant findings enabled the development of a series of suggestions for improving current practice.

1.2.5 Finding the best tool to implement the recommendations

In order to find the most appropriate tool to implement the recommendations, the author studied execution methods for implementation of recommendations, focusing on Management by Objectives (MbO) and Hoshin Kanri or Policy Deployment. Hoshin Kanri or policy deployment was found to be the most appropriate method as it was compatible with the principles by which the research developed.

1.2.6 The Polymer Recycling Hub

An application model was created to provide the framework for bringing together the disparate elements involved in polymer recycling and has been given the name 'The Polymer Recycling Hub' or the 'Hub' for short. It is intended to promote education and re-education of participants in the recycling system as well as fund new ventures, pilot schemes and research opportunities to improve processes; develop new publicity; disseminate information and provide training as required.

The concept of the Hub has been developed as an independent body representing all the major parties within the Polymer Recycling System. It would bring different sectors together, working in harmony to maximise their knowledge, share good practice and create an environment in which innovation could thrive. The Hub would be set up using Dr Deming's[14] principles to develop open and trusting ways of working.

1.2.7 Implementation of the Hub

The Hub would be created using Hoshin Kanri as an implementation technique. In essence this means that members of the Hub would deploy the overall vision by taking individual tasks and devising a plan of implementation. In this way the members would create the plan of action and therefore share responsibility for it. It follows that if they feel responsible for creating a plan then they would have a vested interest in the success rather than merely following an outsider's dictates.

The Hub needs funding and initial money is likely to be provided by the Department of Trade and Industry (DTI) and the Department of the Environment (DETR) or possibly the European Union. The Funding proposal can be found in submission eleven of the Engineering Doctorate Portfolio.

1.3 Scope of the Research

This research focuses on removing plastic from the UK wastestream arising from ELVs, destined for landfill and incorporates automotive shredder residue (ASR), which is rich in plastic, into this scope. It investigates technical and business issues surrounding these materials, analysing the current situation and providing a number of recommendations of areas that need addressing to create an infrastructure capable of recycling the high volume of plastic waste arising from ELVs in the UK.

The research provides a cohesive model that would provide a vehicle to achieve the above and describes a suitable method of implementation. In this way the affected parties can devise the most appropriate methods for them, which would create a working environment to effect change.

Although the later part of this research focuses on a tool to promote change, the work has not incorporated change management psychology or techniques. This was deemed to be outside the remit of the research.

The research does not claim to provide the one and only best method to achieve the developed recommendations. Nor does it dictate how the detail of these recommendations should be actioned in alignment with Hoshin Kanri protocol. However it does give a strategy of issues which, if addressed, could help industry achieve its targets for ELV disposal. This strategy is gaining interest in industrial and governmental sectors.

1.4 The Structure of this project and overview of each submission

The project has been written in twelve submissions excluding this Executive Summary. This section of the Executive Summary will outline the objectives, the scope and the key achievements of each submission in this Engineering Doctorate Portfolio.

1.4.1 Submission one - A Paper published by the Institute of Mechanical Engineers entitled: 'Recycling Implications in the Motor Industry'

This paper was presented to an audience generally consisting of automotive personnel, at a conference within the 1997 Autotech Exhibition, held at the National Exhibition Centre (N.E.C). The objective was to inform the automotive industry of the ramifications of the EU draft Directive, to inform personnel within the automotive industry about what was possible at the time, regarding plastic recycling and opportunities to effect change through design considerations.

1.4.2 Submission two - Copies of a Patent Pending, A Paper and Extended Abstract written about the subject of Recycling Automotive Shredder Residue

This submission contains three documents - a patent application entitled 'Encapsulation Polymer Recycling' No.9817890.8, an extended abstract and a paper describing this process and the findings of the associated research. The objective of this submission is to highlight work carried out in 1997 and 1998 by the author, an undergraduate student and a research associate within Warwick University.

This work focused on finding a use for automotive shredder residue (ASR), which is the material that has been processed through a shredding machine after all the metallic content is removed from the vehicle.

Research on reprocessing ASR using a dual injection moulding process gave rise to a novel method of processing ASR, for which the patent is pending. This is a valuable contribution to the world of automotive recycling as it proves that it is possible to use ASR. This principle is now being further developed by Brighton University[15].

1.4.3 Submission three - Technical Overview of Thermosetting Polymers, Composites and their Disposal Techniques

This defines current practice in the production of thermosetting plastics and their composites. It includes processes used, products produced and looks at methods that can be used to recycle these materials.

This submission specifically concentrates on thermosetting plastics and their composites – it does not investigate thermoplastics, mixed plastic waste or shredder residue.

The key achievement of this submission is to establish a basic understanding of what is currently taking place with regard to thermosetting polymers and their composites.

1.4.4 Submission four - A Business Overview of Polymer Recycling

Submission four is a summary of the findings in submission three and of the author's Masters degree dissertation entitled 'A Business Overview Of Polymer Recycling For The Automotive Industry'. It combines these findings to give a detailed account of the current status of polymer recycling of ELVs.

This submission is primarily concerned with the recycling of automotive plastics, although the author contends that in many instances the study could be used to reflect the state of polymer recycling in general in the UK. It is commonly recognised that the automotive sector's post consumer waste is particularly difficult to reprocess due to the operating environment and age of the material. So it is possible that many of its lessons would be transferable to other sectors.

The key achievement of this submission is to bring together all the findings of earlier work to provide a basic understanding of polymer recycling in the UK. It is clear from this piece of work that technical issues are only one part of the whole polymer recycling infrastructure. Moreover several further and interconnecting issues are identified which appear to prevent the creation of a system capable of coping with the high volumes of plastic waste from the automotive sector.

1.4.5 Submission five – An Investigation of Problem Solving Methods for Analysis of the Polymer Recycling System in the UK.

Submission five is a critique of problem solving techniques and methodologies conducted to find an appropriate methodology for analysis of the Polymer Recycling System in the UK. Any problem solving system adopted must be capable of investigating complex issues with many interweaving aspects and analysing objective and subjective information together.

The author was able to use two methodologies to define the most appropriate analysis tool; a System of Systems Methodologies[16] and Total Systems Intervention[17]. This submission identified Soft Systems Methodology (SSM) as the most appropriate tool for analysing the Polymer Recycling System in the UK.

1.4.6 Submission six – An Introduction to SSM and Mindmaps

The purpose of this submission is to describe SSM in more detail, and show how the author develops her use of SSM on a relatively small scale, before embarking on the major piece of research – the investigation of the polymer recycling industry using SSM.

1.4.7 Submission seven – An Investigation into the UK Polymer Recycling System using Soft Systems Methodology

Submission seven provides an in-depth analysis of the Polymer Recycling System using SSM. This is carried out so that the system can be further understood and improvements to the current system can be made.

Within this submission the author creates a rich picture of the system using information obtained from people with different viewpoints, representing different sectors within the Polymer Recycling System and those affected by this system. The rich picture was created using affinity diagrams and various mindmaps.

The report provides four SSM analyses of issues within the overall Polymer Recycling System, focusing on technical, economic, government and education themes.

This submission does not discuss the recommendations developed from the work. This topic is left for discussion in submission eight.

The key achievements of this submission are as follows. It uses SSM to provide an in-depth understanding of the current Polymer Recycling System – highlighting peoples' views, beliefs and judgements. The submission uses this information to provide recommendations of how to move from the current state to the preferred one. A literature search has shown that SSM has not previously been used to investigate the Polymer Recycling System in the UK.

This submission has also used mindmaps with SSM to create the rich picture of the Polymer Recycling System. A literature search has that there has been no published work that has combined the use of mindmaps with SSM.

1.4.8 Submission eight – Recommendations for Improvement of the Polymer Recycling System in the UK

This submission brings together the findings and recommendations from the SSM analysis for improvement of the Polymer Recycling System in the UK. It provides an overview of the recommendations that collectively could provide society with a workable solution to a real life national issue by helping to overcome the issues found in the SSM investigation.

1.4.9 Submission nine - An Investigation into Implementation Techniques for the Polymer Recycling System

This report describes methods that are used to implement socio-political solutions at policy level. An investigation into strategy implementation identified Management by Objectives (MbO) and Hoshin Kanri.

Hoshin Kanri is selected as the implementation technique for the Polymer Recycling System. It has distinct advantages over MbO and is a continuation of the philosophy developed by the author throughout her research, being specifically compatible with the principles of SSM.

1.4.10 Submission ten –The Use of Hoshin Kanri to Deploy Improvement Recommendations for the Polymer Recycling System – The Polymer Recycling Hub

This submission describes the use of Hoshin Kanri as an implementation technique for the deployment of improvement ideas for the Polymer Recycling System. It describes the creation of a Polymer Recycling Hub, capable of helping industry and other sectors of UK society work towards meeting and surpassing legislation targets and raising awareness of plastics recycling in general.

This submission describes how Hoshin Kanri could be used as an implementation tool in this process but does not attempt to provide a detailed and structured plan of action as this would be against the underlying philosophy of the tool and is outside the remit of this research. However it does reveal who could be involved, what resources would be needed and provides a model of the Polymer Recycling Hub. This model could be further developed by those involved in the Polymer Recycling System and the detail developed using Hoshin Kanri as the deployment tool.

The main achievement of this submission is to provide a cohesive vision of a body that could change the Polymer Recycling System in the UK in order to meet legislative targets. This is the first documented description of a such a body that sets out to lead the UK towards meeting government targets for polymer recycling of end of life vehicles.

1.4.11 Submission eleven – Demonstrating the Application of Knowledge

This submission provides copies of documents created to deploy the Polymer Recycling Hub and to gain backing on a financial and non-financial basis. It contains a business plan which has been put forward to the DTI and the DETR and is to be forwarded to the WRAP (Waste Resource Action Programme) funding initiative (a joint DTI and DETR venture). It provides a proposal for a Polymer Recycling Network, which has subsequently been accepted by the EPSRC and is currently in existence, based at the University of Warwick and an internal paper describing the need for a 'polymer recycling centre of excellence'. This submission also provides a copy of a presentation given in September 2000 to the Automotive Recycling Taskforce within the British Plastics Federation.

The main achievement of this submission is to demonstrate the author's actions, carried out in order to effect change in the UK Polymer Recycling System and to bring the Hub into existence. It also shows the associated interest from industry, government and education establishments.

1.4.12 Submission twelve - Personal profile

Submission twelve provides an account of how the author has developed on a personal level, during the five years spent on the Engineering Doctorate programme. It gives a summary of previous educational and industrial experience, prior to embarking on the Engineering Doctorate.

The emphasis of this submission is to demonstrate how the author has developed and achieved the competencies required to meet the Engineering Doctorate requirements. These include expert knowledge of an engineering area, application of industrial engineering and development culture, project and programme management skills, teamwork and leadership skills, communication skills, organisation skills, financial engineering, project planning and control, application of skills and knowledge to new and unusual situations, ability to search relevant information sources and the ability to develop optimal solutions to complex engineering problems.

The key achievement of this submission is to highlight the learning that the author has achieved throughout the Engineering Doctorate programme.

1.5 Order of reading submissions

The list of submissions as outlined in section 1.4 is in the order in which they should be read. The author believes that each submission builds on the research into the Polymer Recycling System in the UK.

However, submissions 1, 2, and 3 are primarily background reading and are therefore not pivotal to the main themes of this Engineering Doctorate Portfolio. All the other submissions are necessary reading, in order to gain a full understanding of the overall process of research and results achieved by the author.

2 Technical Issues of the polymer recycling industry

This chapter provides an overview of the information found in Submission 4 of the Engineering Doctorate Portfolio.

Polymer recycling is a relatively new concept to our society since polymers have only been used in volume for the past 60 years[18]. The term 'recycling' can be split into 5 categories to form a Hierarchy of Use strategy as outlined by the EU Directive[6], beginning with the most desirable as shown below:

1. reuse
2. mechanical recycling
3. chemical recycling
4. feedstock recovery
5. energy recovery/incineration

2.1 Reuse

Reuse occurs when a product is reused in its original form. The component is removed from the waste stream and is resold to the market to perform its original function. For example, a vehicle that has reached the end of its life may have its door handle removed, resold through a dismantler and placed onto another vehicle.

This is the most desirable of recycling methods according to the European Directive, due to the low direct processing costs associated with reusing a component. However, quantities of specific components cannot be guaranteed in the right place at the right time and can be costly to transport. Also, parts can be damaged during the removal process and some plastic components may degrade over time depending on their composition, workload and environment.

2.2 Mechanical Recycling

Mechanical recycling reduces plastic waste into smaller parts, which can be reprocessed and reformed to produce new products. Generally thermoplastics are sorted into similar material types and heated until they can be reformed. Thermosetting plastics on the other hand tend to be sorted into similar types, granulated and then reformed using a liquid virgin thermosetting polymer to bind the granules together and act as glue.

Mechanical recycling is currently the most popular type of recycling due to the relatively low cost of setting up the process and reprocessing the material, when compared to chemical recycling and feedstock recovery.[19] There are approximately 25 generic types of plastics and within each group there are many possible variations depending on the types and amounts of additive and pigment contained within the polymer. These factors create material compatibility problems, and therefore materials can require several additional segregation stages prior to processing.

2.3 Chemical Recycling

Chemical recycling uses chemicals to break the long polymer chains into smaller units - known as monomers. These can be subsequently reprocessed to form materials capable of use in the production of engineering components and products. The polymeric product from chemical recycling is not necessarily an inferior grade than the original spent plastic being recycled.

Chemical recycling is of particular use for thermosetting polymers and elastomers as it can break the cross-linking networks that are often mistakenly thought to be irreversible.[20]

There are three main methods of chemical recycling - Hydrolysis, Glycolysis/Alcholysis and Aminolysis. The three methods require segregated waste plastic to be exposed to water, glycol/alcohol or amine respectively at elevated temperatures and pressures. There are very significant potential health and safety implications and to achieve a safe system capable of reprocessing in this manner, a high initial investment is required. This means chemical recycling is currently carried out on a small scale.

2.4 Feedstock Recovery

Whereas the technical use of the word recycling may be defined as: ***reusing the polymeric content of the waste material in a recognisably plastic form***, recovery concentrates on reusing the oil, hydrocarbon or calorific content within the waste material.

The advantage of feedstock recovery is that it can be used directly on mixed plastic waste (MPW) without pre-cleaning or processing. However, it is currently not thought to be a cost effective method of disposing polymeric waste, due to the high temperatures and health and safety precautions needed for the process, which lead to high capital layout and running costs[5]. Therefore, at present operators of feedstock recovery systems have to charge a high gate fee (a charge levied by the recovery plant to process the waste polymeric material) to make their systems financially viable.

2.5 Energy Recovery

This method of recovery releases and uses the energy contained within the polymeric waste, through incineration. It is estimated that the average calorific value of MPW is 35MJ/Kg which compares well to that of 29.5 to 41 MJ/Kg for coal and fuel oil[5]

Many countries throughout Europe use municipal solid waste combustors, which can burn polymeric waste as well as other waste stream materials. Energy recovery can occur for example, when the combustor is linked to a localised heating system for the supply of hot water and process steam. Certain areas in Paris, France have equipped residential buildings with combustors, which incinerate the domestic waste and provide low cost heating for the residents.[5] In the UK, Peugeot in Coventry is also equipped with a combustor whereby energy is recovered and used within the plant.

However these combustors are designed to cope with waste that has a calorific value of 6-12 MJ/kg. As plastic waste has an average calorific value of 34MJ/kg, there would need to be an extra process to mix the ELV plastic waste with another waste source containing less latent energy.

Alternatively the ELV polymeric waste could be used as a fuel in specially equipped municipal waste incinerators. However, there are currently only twelve of these incinerators in the UK and they are currently charging approximately £40-50 per tonne for shredder waste[7]. They are likely to charge even more for ELV polymeric waste to enter their incinerators as the incineration process needs to be turned down in order for the system to cope with the high calorific level of this material[21]. This is not thought to be cost effective when compared to the landfill charges of £20 - £25 per tonne[22].

Other possible energy recovery options include adding polymeric waste to the steel industry's blast furnaces and to the cement manufacturing process. However there are drawbacks - there is only one blast furnace operational in the UK capable of coping with ELV waste plastic and that is likely to charge a fee for usage[23]. In cement manufacture, the addition of post consumer plastic waste has been called into question in the UK by the Environment Agency[24] on pollution grounds.

2.6 Design

The technical processes highlighted in the earlier sections of chapter 2 are extremely important when considering recycling polymeric materials. But a further consideration is design, which is important on two levels for recycling: design for fast and easy dismantling (disassembly) of spent products and design using recycled plastics.

2.6.1 Design for disassembly (DFD)

The European Directive states that 'Producers should ensure that vehicles are designed and manufactured in such a way as to allow the quantified targets for reuse, recycling and recovery to be achieved'[6]. This means that vehicle manufacturers and their suppliers will eventually be legally bound to ensure they design for recycling.

The design of a product at the beginning of its life will affect the ease of disassembly when it reaches the end of its life. Parts should be designed so that they can be quickly removed from the spent product, without adversely affecting its quality or life in service.

Designing current products for recycling will have a long-term positive effect on the recycling industry. For example, a car that is currently being designed will reach the end of its life in approximately 14 - 21 years[1]. So by designing easily recyclable cars today, the recycling task in 14-21 years will be easy compared to today.

The design of a product will also affect the recyclability of that product when it reaches its end of life. Ideally the following guidelines on items to avoid should be followed:

- the encapsulation of metals and other non plastic materials, with polymeric materials
- clips and other fasteners (including adhesives) manufactured from materials dissimilar to those used in the construction of the component
- components which cannot easily be removed from the assembly or product of which they are part.
- dissimilar polymeric materials used to manufacture components. For example, the interior trim of a car door is likely to be made from 3 or more layers of different types of plastic which would have to be separated prior to recycling. This can be avoided with careful design.

2.6.2 Designing with recycled plastic

When using recycled polymeric materials, the material capabilities should be considered to be different to that of the original material. Recycled polymeric material often behaves differently to virgin polymeric material and these differences have to be understood and exploited to create equally good or even better products. Thus the design engineer needs expertise in working with recycled plastic and the knowledge to choose the grade and type of recycled plastic appropriately.

2.6.3 Automotive components that could be manufactured using recycled plastic

The information in figure 2 shows which components could be manufactured from recycled polymeric material[17].

	Polypropylene (PP)	Polyurethane (PU)	ABS	Nylon
Bumpers	✓	✓		
Wheel Trims	✓		✓	✓
Number Plate Holders			✓	✓
Instrument Panels	✓	✓		
Seat Foam		✓		
Vents, Housings	✓			
Battery Housing	✓			
Wheel Arch Liners	✓			

Figure 2. Examples of vehicle components that could be made from recyclate

Source: ATO's Understanding Plastics 1997[25]

Polypropylene, Polyurethane, ABS and Nylon are four of the most commonly used plastics in the automotive industry. Thus plastics from ELVs could be reprocessed and mechanically recycled for automotive use.

2.6.4 Transportation

Figures from the CARE Group[i] suggest that the transportation of 4 tonnes of ELV plastic waste will cost about £200 per load. Delivery from the reprocessing plant to the moulders is thought to cost about £10 to £15 per tonne. This reduction in transportation costs is due to the increased density of the granulated plastic material. Road transport of unprocessed spent material is

i. [i] The Care Group (Consortium of Automotive Recycling) is a partnership of 15 automotive manufacturers and 31 dismantlers which was established in 1995. It aims to provide real solutions to aiding dismantling and recycling of vehicles.

therefore expensive due to the low packing density of the material and should be avoided where possible.

Recycling any material is a means of achieving environmental goals such as landfill avoidance, raw material and energy conservation. It is important to keep the energy consumption of transportation to a minimum, therefore the packing density of the material should be maximised.

In order to reduce the transportation costs of spent material, each dismantler could use a granulating machine that would grind plastic components into 3-10 mm diameter pieces. If there were several different types of plastic needing transportation, these granules could be placed in containers to be directly loaded onto the trucks. In this case the containers could be manufactured from an appropriate waste plastic source. Alternatively, if sufficient quantities of one specific plastic are to be transported, the waste plastic could be directly placed into bulk carriers. Either way, this would increase the capacity to store segregated material at the dismantlers and increase the packing density for transportation, thereby reducing costs and increasing the amounts that trucks can load and carry.
However, if the dismantler only owned one granulator, it would need careful cleaning after use so that the polymeric generic types remain segregated. If, on the other hand, the recycling process is huge then it may justify the purchase and use of several granulators at the dismantler, each dedicated to one generic type of polymer.

2.6.5 Reprocessing the polymer

As stated earlier, mechanical recycling is currently the preferred method for recycling plastics. Generally, plastics are manually removed from the wastestream and separated[26]. They are then granulated, cleaned and reprocessed using the methods outlined in section 2.2.

In order to keep the energy consumption and labour costs down, reprocessing should be simple, fast and kept to a minimum of stages. Sorting, separation and reprocessing would ideally be mechanised and wherever possible cleaning should be kept to a minimum, whilst keeping the material within the required specification.

2.7 Technical conclusion

There are many known techniques for recycling plastics. However, a large amount of work has to be carried out on technical and process development, as well as optimising design knowledge and transportation issues, in order to create a recycling industry that will be successful in removing the polymeric materials from waste streams currently destined for landfill sites.

3 Business issues

Chapter 2 has shown that there are several techniques for recycling polymeric material and that products can be designed for recycling. Although these are highly important factors of the Polymer Recycling System, there are other issues to address before UK and European industry can cost effectively process large volumes of polymeric waste material from spent products.

This chapter concentrates on the interweaving economic and business related issues. Further detail can be found in Submission 4 of the Engineering Doctorate Portfolio.

3.1 Legislation

The UK automotive industry is expecting primary legislation for the disposal of end of life vehicles in the year to be introduced within the next 12 monthes[27]. The motor industry would have preferred a voluntary agreement stating their aim to achieve maximum levels of ELV material entering landfill matching those specified by the directive, but the directive was presented to European Parliament (Brussels) in the year 2000. Supporters of the EU Directive were concerned that the voluntary agreement would not have been legally binding, with no penalty set for non-conformance. When UK legislation is enforced, there will be definite penalties for the motor industry, if targets are not met.

Overall, the author believes that legislation will be needed to initiate the development of a Polymer Recycling System that can reprocess the high volume of plastic waste from ELVs and be cost effective in the long term.

3.2 Dismantling and reprocessing

The speed and ease with which polymeric materials can be removed from an end of life product will dictate the dismantling costs. Therefore, the methods used to remove the polymeric material are of paramount importance in order to obtain maximum material in the shortest period of time. This topic is closely related to the issues stated in sections 2.6.1 and 2.6.5.

The amount of reprocessing needed to manufacture with recycled polymeric material will affect the cost effectiveness of the recycling system and its product. For example, if the material has to be separated into generic polymer families such as Polyester, Polypropylene etc. reprocessing will take more time than if separation is not needed and time will add to the costs. Also, if a cleaning process is required, reprocessing costs will be greater. Reprocessing operations should thus be kept to a minimum.

3.3 Market creation

The recycled polymeric material must be used, though its form will depend on the recycling process. There is no point in producing a recycled polymeric material, if there is no demand for the finished product. Therefore, markets have to be found that use recycled plastic. If the material has an associated demand then it will have some financial value attached to it.

3.4 Financing

In order to develop and create new polymeric recycling initiatives, financial support will be required for capital outlay and other set up and overhead costs. This money could be made available through Government funding or private/Government financing.

It can be seen in areas such as health care and space travel that government granted funds can sometimes place the emphasis away from finding cost effective solutions promoting, instead, a 'find an answer no matter what the cost' attitude. Private sponsorship may be a more effective way to advance the recycling industry in a manner that maximises efficiencies and cost effectiveness.

If the aim is to enhance cost effectiveness and profit making, then the preferred route would be a system of industry or government financing where loans are made available at low interest rates with long pay back periods.

If government decides that polymeric recycling is a social issue, which need not necessarily be profit making, then funding for set-up costs could be drawn from either direct or indirect taxation. This could encourage more novel types of recycling, reduce the financial pressure upon the industry and promote the long-term improvement of technologies. It is thought however that money obtained from recycling once operations were established could offset costs incurred and therefore long-term government funding may not be needed.

The Government is beginning to provide funding for recycling initiatives, in the form of DTI funds (currently £1.4 million). This is for the recycling of all materials from all sectors, not specifically polymeric or automotive waste. As a result over 250 bids have been put forward for research projects of which 7 have been chosen for funding [28]. There are 2 plastics-related projects of which the author is now managing one.

Other funding is becoming available from sources such as ENTRUST[u] for recycling projects. However, plastic recycling is considered to be difficult when compared to that of metal, glass and paper and therefore few polymer recycling projects are being supported. An opinion put forward by the Chairman of the CARE Group, points out that government officials who want quick results from their spend of the fund are unlikely to put forward large sums of money for plastic recycling research projects[29]. However, as UK legislation begins to develop the DTI and DETR are becoming involved in the issues surrounding ELV recycling. It is therefore inevitable that they also become involved in plastic recycling of ELVs for the reasons stated in 1.1.3.

It is the author's opinion that a combination of funding and financing from private sponsorship (industry) and the Government would provide the best solution. The recycling industry should aim to create and develop innovation and become self-supporting and profit-making in the long term, to achieve self-sustainability. Funding routes for the development of innovation and financing should be made available to foster long-term development of a cost effective and profit making plastic recycling industry.

3.5 Subsidisation of ELV polymeric recycling

The recycling of polymeric materials is one part of the recycling of a whole product. The metal recycling industry is a well established and company driven activity. It is capable of generating profits, although this involves a delicate financial balancing act because virgin metals can often be bought at comparable prices[29]. If the disposal of the whole product were taken into account, rather than the polymeric material alone, then the combined recycling of polymeric materials and metals could allow many of the overheads that would arise from polymer recycling alone to be offset by existing investment and cash flows in the metal recycling industry. For example, the overall disposal of a vehicle at the end of its life may be profit making, whilst the recycling of the plastics alone may not be profitable. Therefore, it may be advisable to look at the economics of recycling the whole vehicle rather than just its polymeric content. If this is the case then the plastic recycling of ELVs could be developed primarily by those responsible for recycling the metal (say the shredders).

Alternatively, government could create a system for even distribution of profit throughout the ELV recycling industry. However, this would be in conflict with the EC Directive, which has made industry responsible for ELV disposal and meeting legislative requirements. In doing so, government has effectively given industry the freedom to distribute profits and losses in the manner that they choose.

Another method that government could use to promote the plastics recycling industry is to tax virgin plastics sales in this country, and/or subsidise use of recycled plastics in the marketplace. This may not be perceived by government as politically acceptable and is bitterly opposed by virgin plastic producers.

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ii. [ii] ENTRUST is a not-for-profit company that regulates the landfill tax credit scheme in the UK. It uses part of this money to fund projects that conform to the environmental objectives as defined by H.M Customs and Excise.

3.6 Responsibility for disposal of spent material

The 2000 European directive states that the 'economic operators' are responsible for ELV as defined in 2.1.3 of this report. Neither the European Commission nor UK Government has yet specified how this will be implemented but this is expected to be clarified in the UK legislation within the next 12 months.

As the UK's economic operators are being made responsible for ELV disposal through legislation, they will have to find solutions for the issues outlined in this section. As they are profit making organisations, they will want the solutions to be cost effective and profit making, wherever possible, in order to benefit from this system in the long term.

However, an interest yet to be addressed is the involvement of small component manufacturers (of items such as nuts and bolts) who may not even be aware that their components are being used in the motor industry. It seems unlikely that they will be apportioned the same responsibility as the vehicle manufacturers for ELV disposal, as their overall contribution to the production of a vehicle is limited. This illustrates the need for a clear definition of producers.

Apportioning responsibility in the way outlined above would provide the incentive to design for recycling and disassembly and could also lead to the creation of demand for recyclate by the economic operators. This is because economic operators will have a vested interest in ensuring that legal disposal targets are met and they can actively make a difference by closing the loop and recycling the very same plastic they are responsible for, back into their new products.

ELV landfill avoidance has been made the responsibility of the economic operators even though they oppose this legal definition. However, it will be an extremely complicated responsibility to enforce as it covers such a wide section of industry with so many different parties involved – each with different roles and values/objectives - and some having a more direct role to play than others. UK legislation will need to be written in such a way that ambiguities are minimal.

3.7 People's perceptions

The perceptions of the different sectors of people in the UK, when focusing on polymeric recycled materials, needs to be more clearly understood in order to highlight any difficulties associated with changing the status quo. From the author's networking in the automotive and polymer recycling world, it is clear that there are a variety of different beliefs, values and judgements being used to define people's opinions of recycling plastics.

The author is of the opinion that these disparate perceptions may create barriers to establishing a Polymer Recycling System of sufficient capacity to cope with ELV waste. By understanding people's perceptions and presenting objective evidence of fact it may be possible to breakdown such barriers.

3.8 Conclusion

Even if legislation were introduced immediately into the UK, it would not be possible to achieve the landfill levels stated in the draft ELV directive. Moreover, ELVs are just one of the 7 priority waste streams. This is not primarily due to technical limitations, but to the highly complex, interwoven business and process issues.

This is a field where limited research has been carried out to date and there is a clear need to form a holistic view of the recycling industry, including an understanding of the subjective issues surrounding the Polymer Recycling System, in order to overcome specific problems that are currently preventing industry from recycling polymers.

4 Research to find appropriate problem-solving technique or methodology for the Polymer Recycling System in the UK

The author saw a clear need to understand further the softer issues of the Polymer Recycling System. Work began by defining the word 'system' in problem-solving terms and then proceeded to define the Polymer Recycling System in this manner. This was followed by an investigation of the various tools, techniques and methodologies with a view to finding one appropriate for analysing the issues surrounding the Polymer Recycling System. The following is an account of this section of the research. Further details can be found in Submission 5 of the Engineering Doctorate Portfolio.

4.1 Definition of the word 'System'

The term 'system' is a common word used in a variety of ways. However the author will use the definition which means "a particular way of organising our thoughts about the world"[17]. This fits with Jackson's definition that 'systems are seen as the mental constructs of observers rather than as entities of an objective existence in the world'[16].

This definition takes into account the fact that we live in a world where objective 'things' are found alongside subjective values and beliefs. In real life scenarios, it is seldom possible to separate these and, indeed it is often beneficial to consider them together. Thus the word 'system' will be used in this document and further doctoral research to organise objective or 'hard' issues alongside subjective or 'soft' issues, as they are found in the real world.

4.2 Summary of Polymer Recycling in the UK in Systems Terms

There are many interweaving layers of information in the current UK Polymer Recycling System. Economic, technical, political, ethical and the environmental issues all figure strongly in this context, with each topic closely related to the others, often interconnecting and sometimes inseparable. This is a very complex and disordered problem state with many unknowns both in the present and the near future (notwithstanding imminent introduction of UK legislation[iii]). The problem state is a national one that has implications for the UK community. (In fact it is an international one, but for the purposes of this research the author has chosen to confine the system boundaries to national level).

There are a number of different key groups and/or industries involved and each has marginally different needs and goals, although the overall requirement for the creation of an effective Polymer Recycling System is common to most. Indeed, to many parties this may be key to their competitiveness and possibly even their survival if this becomes threatened by enforcement. Thus it is important to take the subjective aspect of the Polymer Recycling System into consideration as a vital part of the overall system.

Not only is the problem-state complex but the way forward is not clear. There are many possible changes but no one single way forward. In the author's experience, the only goals that are even loosely agreed are those to achieve legislation target levels and to do so without losing money or, better still, to make money.

4.3 The Review of appropriate problem solving techniques and methodologies

The author investigated hard and soft methodologies and organisational cybernetics in the quest to find one able to analyse the Polymer Recycling System in the UK. Hard techniques and methodologies were found inappropriate as they only analysed the objective aspects of a system rather than the mixture of objective and subjective matter.

Organisational cybernetics, which investigates the relationship between man and the machine, was felt more appropriate for developing an understanding of the complex issues surrounding the Polymer Recycling System than the hard problem solving techniques and methodologies. It treats the total system as a complex entity and can be used to show it as a holistic interweaving model.

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iii. The term *UK Legislation* is used for the sake of concision. Where reference is made to UK Legislation or similarly implied concepts, this should be read as meaning legislation of England and Wales, Scotland, and Northern Ireland together or separately, as appropriate.

However, it still focuses on the complex non-human aspects of a system and does not incorporate a full methodology that could be used to develop recommendations for improving the current situation.

Soft problem solving techniques and methodologies were next investigated. Strategic Assumption Surfacing and Testing (SAST), Social Systems Sciences (S^3) or Interactive Planning (IP), Critical Systems Thinking or Critical Systems Heuristics (CSH) and Soft Systems Methodology (SSM) are considered below.

4.3.1 SAST

SAST is a soft problem solving technique that is particularly useful when there are many parties involved in a simple system rather than complex situations[17].

SAST is limited in that only the assumptions that are agreed upon by all parties are taken into account. In the polymer recycling world, it is unlikely that all the parties will agree on everything. However, this would not necessarily mean that an assumption is not relevant, merely that not all groups agree with the assumption. Because of the likelihood of low levels of consensus, it is unlikely that SAST would help to create synergy within the polymer recycling world.

Leading on from this limitation, it would appear difficult to achieve total synergy at the end of the investigation using SAST, particularly in the polymer recycling world where there are a variety of views and assumptions from different groups within the system.

SAST appears to lean towards management bias and does not appear to support fully the philosophy that everyone involved in a system has the potential to give relevant information that will enhance the investigation[30]. Therefore it is likely that there are other problem solving techniques that will be better suited to addressing the Polymer Recycling System.

4.3.2 Social Systems Sciences (S^3) or Interactive Planning (IP),

IP, as this soft problem solving technique is commonly known, was developed by Ackoff and is essentially a more complicated version of the commonly used gap analysis tool. This is a reasonably simple tool that is easy to understand and simple to implement.

Overall, IP appears to be a useful tool for complex and disordered systems that are man and machine based. It can potentially be used by any of the people who operate within the system or an outsider. However, IP does not cater for situations where there is a conflict of interest, but instead bases its technique on a world of consensus[17]. In the case of the Polymer Recycling System, IP is of limited value since all parties do not agree and they have different vested interests in their roles within the system.

IP is also not designed to take into consideration any environmental or political drivers that are prevalent in the Polymer Recycling System. Therefore, the resultant model would not necessarily reflect the real world issues involved. . IP would therefore be best used where all parties agree upon the objectives and planning, or where there is a genuine wish by all affected parties to compromise.

4.3.3 Critical Systems Thinking

Critical Systems Thinking and Critical Systems Heuristics (CSH) were not designed to make sense of disordered and complex issues. The first stage of CSH begins after the situation has been assessed and a plan or potential plan is created. Therefore CSH is more of a refinement and implementation tool than a total systems methodology.

This problem solving technique is best used in an environment where there is a general consensus of opinion, as it gives no indication of how differences in motivation and objectives would be taken into account.

So, CSH is to be used once a plan has been created. It can test these plans against four basic assumptions by both the planner/systems analyst and the people affected by the system. CSH takes into consideration the ethical and social aspects of problem solving but lends itself to relatively simple and non-political environments where there is general accord.

4.3.4 SSM

SSM is a tool that can be used to develop an understanding of a complex and disordered situation. The emphasis on collecting data via participation from people within and affected by the system at the earliest stage, means that a view of the current situation can be built up, including cultural and political issues.

SSM is a method of defining a situation, deciding what the ideal should be and what it could be, and performing a gap analysis on this to see how the gap could be closed. This is particularly useful if there are no or few clear-cut objectives of how the system is to develop, as in the case of the Polymer Recycling System.

The author has found several criticisms levelled at SSM[17].

The first criticism is that issues of conflict and coercion are not ‘properly addressed’. It is possible to ignore matters of conflict using SSM, if the practitioner only gathers information from some of the affected sectors within the system, or if the practitioner is unable to get people to express their feelings (for reasons of fear or peer pressure).

However, it does appear that issues of conflict are likely to be brought out at the first stage of SSM when the practitioner is gathering subjective and objective information from those affected by the system under investigation. Also, at a later stage it is possible to investigate how changes can be made from current to ideal world-state, which can specifically take into account the conflict. Therefore it appears to the author that issues of conflict are indeed catered for in a manner that is better than any of the other problem solving techniques currently available.

Another critic suggests that SSM does not specify who should participate in SSM. They then elaborate to say that the ‘methodology will always serve those with power in a social situation’[17].

The initial point appears to be precisely the point of SSM and indeed Churchman states that 'there are no experts in systems analysis'[30]. In fact, it seems strange that these authors cite this as a criticism, as it would appear that the flexibility created by being non-prescriptive is a benefit. The second belief that it will serve those in power may be true if a few people were chosen to participate, but this would suggest that the analyst had already decided the outcome and the whole investigation would then be basically flawed, as the analyst is biased. However, this would also be the case with any of the problem solving techniques described in this document.

Overall, it appears that SSM is the problem solving technique best-suited for investigating the Polymer Recycling System. The author therefore tested this theory by using two methodologies designed to help the systems analyst choose an appropriate problem solving technique or methodology. These systems are known as a System of Systems Methodologies and Total Systems Intervention.

4.3.5 A System of Systems Methodologies

A System of Systems Methodologies sets out to describe the system under investigation using a number of different metaphors. These are as follows:

- Simple – having a small number of elements with few highly organised interactions. The system does not evolve over time, is unaffected by inside or outside influences and there are well-defined laws that control performance.

- Complex – having a large number of elements with many disorganised interactions between them, which can be problematic in nature. The system evolves over time, is subject to internal and external influences, where sub-systems have their own objectives.

- Unitary – Sharing common interests, with highly compatible beliefs and values, in harmony on decision making where all members participate and have a single shared vision where each member acts in alignment with the pre-determined goal.

- Pluralist – Having a fundamental shared interest, where values and beliefs are shared to a degree. Compromise is possible even though there are some disagreements. All parties are involved in the decision making and each member acts in alignment with the pre-determined goal.

- Coercive – Common interests are not shared, there are conflicts in values and beliefs, there is little agreement and compromise is at best unlikely. There is likely to be pressure placed by some on others to conform and there is no possibility in the current state to agree on objectives.

The Simple, Complex metaphors can be grouped with the Unitary, Pluralist and Coercive metaphors to give a matrix as can be seen in figure 3.

	UNITARY	PLURALIST	COERCIVE
SIMPLE	Simple / Unitary	Simple / Pluralist	Simple / Coercive
COMPLEX	Complex / Unitary	Complex / Pluralist	Complex / Coercive

Figure 3. Matrix of Metaphors- Source: Flood, R.L. and Jackson, M.C. Creative Problem Solving – Total Systems Intervention, 1995:35)

Using this System of Systems Methodologies and looking back at the definition attributed to the Polymer Recycling System (in systems terms) above in section 4.2, it is clear that the Polymer Recycling System is complex and pluralist in these terms.

According to Flood and Jackson[17], there are two suitable methodologies for systems that are complex / pluralist, which are Interactive Planning and SSM. The author has already disregarded IP due to its inability to cope with conflict and political issues. So it appears that using the System of Systems Methodologies, the author can confirm that SSM is the most appropriate tool for investigation of the Polymer Recycling System.

The second methodology for finding an appropriate problem solving technique is called Total Systems Intervention.

4.3.6 Total Systems Intervention (TSI)

This is a problem solving methodology that looks at the system to be investigated and provides a method of matching the best suited problem solving technique(s) to that system under investigation.

- Stage 1. - Creativity

The basic question at this stage is 'what type of organisation is the Polymer Recycling System?' In TSI terms the following metaphors are used:

1. Machine or closed systems that would be goal driven typified by scientific management style.
2. Organism or open system where the primary aim would be survival rather than goal driven as in 1.
3. Brain, Cybernetic or 'viable' system that would be dynamically goal driven – learning to learn.
4. Culture system where the emphasis is on values and beliefs and coalition.
5. Team or Political system where the emphasis of the system is political and united.
6. Coalition system where the emphasis of the system is political and with diverging interests but with a mutual focus, causing coalition in a loose form.
7. Prison system where the emphasis of the system is political with conflict and uneven distribution of power.

In comparing the system definition of the Polymer Recycling System given in section 4.2 with these metaphors, the author concludes that it is strongly 2 and 6 (organism and coalition) due to the nature of the automotive industry and the focus created by the EC Directive. It certainly isn't a 1 or a 7 (closed or prison) and it is not yet a 3 (learning organisation), although it could be in the future. It has a slight bias towards being 4 (a culture system) although this is not as strong as 2 and 6.

So in summary the Polymer Recycling System is strongly an organism and coalition system with a leaning towards being cultural.

- Stage 2 – Choice

TSI uses the System of Systems Methodologies in this stage, which has been carried out previously in section 4.3.5. The findings from this analysis were as follows: the Polymer Recycling System is complex and pluralist in nature using the metaphors outlined earlier in this section.

- Stage 3 – Implementation

Putting stages 2 and 3 together, it is possible to create a framework that shows how the problem solving techniques discussed in this report can be used for different types of problem situations. The author has created a framework that can be seen in figure 4.

System Methodology	System of Systems Methodologies metaphors	TSI underlying metaphors
Hard Systems Tools such as SD	Simple / Unitary	Machine or closed system Team or Political system
Organisational Cybernetics including VSD	Complex / Unitary	Organism or open system Brain, Cybernetic or 'viable' system Team or Political system
SAST	Simple / Pluralist	Machine or closed system Coalition system Culture system
IP	Complex / Pluralist	Brain, Cybernetic or 'viable' system Coalition system Culture system
SSM	Complex / Pluralist	Organism or open system Coalition system Culture system
CSH	Simple / Coercive	Machine or closed systems Prison system

Figure 4. Table showing that each methodology is best suited to particular types of systems. Source: Flood and Jackson 'Creative Problem solving – Total Systems Intervention'.

From figure 4 it can be seen that SSM is the most suitable problem solving technique for carrying out an in depth investigation into the Polymer Recycling Industry. This adds weight to the author's findings from her own critique of problem solving techniques and methodologies and from application of a system of system methodologies. SSM was therefore the tool that the author used to model the Polymer Recycling System in the UK and to develop suggestions for improvement.

5 Analysis of the Polymer Recycling System using SSM

SSM is a rigorous problem solving/continuous improvement tool that has seven stages within it, which are shown in figure 5. Full details can be found in submissions 6 and 7 of the Engineering Doctorate Portfolio:

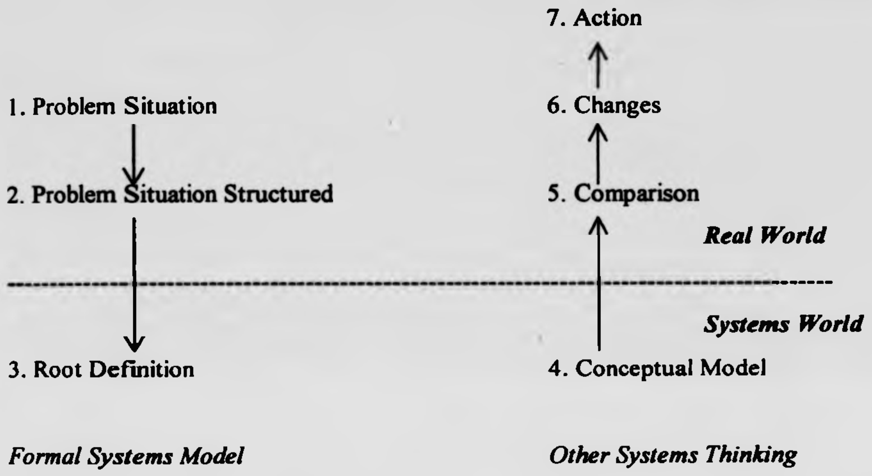


Figure 5. Stages of SSM Source: Adapted from C.J. Atkinson and Checkland P.B. "Extending the Metaphor 'System'" Human Relations, 1988. 41:10. 713[31]

5.1 Problem Situation

This is where the situation is first defined in SSM terms. For the Polymer Recycling System, the author spoke to a variety of different people from different sectors, who included:

- Experts - people who are considered in the business as experts of plastics and automotive recycling (people sitting on the British Plastics Federation's Automotive recycling taskforce and members of the Consortium of Automotive Recycling).
- Design Engineers- people in the automotive industry who design or have designed various components within vehicles

- Moulders - people involved in the manufacturing process of plastic components
- Research Engineers and scientists- people working within a research establishment
- General Public
- Schoolchildren

The author conducted an informal survey at the Motor Show in 1998 and a Coventry school. The survey was not absolutely rigorous in method - its intention was simply to demonstrate the diversity of opinions that can be gathered from a non-representative subset of people, rather than seeking to gather a "representative" set of opinions.

The people who were questioned were asked to write down what plastics recycling meant to them. This very open question was deliberately used, in order to give people the individual freedom to choose what they wanted to say, and the manner in which they wanted to say it. Defining the problem situation in this way yielded a large amount of data that was later structured to gain a better understanding of the information.

The author questioned a variety of people from the different sectors, but it was not possible to talk with every single individual who has a view on ELV plastics recycling. However, this is one of the strengths of SSM, which accepts that it is never possible to gather all the information from any given system, but instead provides a tool where complex and ill-defined issues can be better understood and analysed[32].

There is a danger, if only a few groups of people are included in the investigation, that the analysis would yield biased results. In the case of the Polymer Recycling System, the major issue that appeared to surface from preliminary background research over the initial eighteen months was a variety of different beliefs and perceptions held throughout all the affected sectors. It is distinctly possible that there are even more alternative views to be found by interviewing further people. However, the generic recommendations that come from the SSM analysis are likely to benefit all those affected. (Please see Submission 7 of the Engineering Doctorate Portfolio for further description).

As an example, five comments were given by those who were questioned and have been chosen to reflect the contrasting views. These are quoted below:

1. No demand for recycled plastics.
2. Not economic good sense to recycle but a legislative necessity.
3. Public perception of plastics applications not good (often seen as cheap and tacky).
4. Needs to be cost effective.
5. Investment required for new facilities for recycling is significant.

These five issues will be followed through this section of the report, to give examples of how the author applied SSM to the Polymer Recycling System. These comments (and many others) were collected and collated from the responses in order to structure the information.

5.2 Problem Situation Structured

The information was collated and key words were taken from the responses, which were used to create an affinity diagram. Grouping revealed general themes and gradually main themes began to emerge.

From the affinity diagram, the information was structured further using mindmaps to draw out the key headings and show the information from this. The collective group of mindmaps and the affinity diagram together will be referred to in this report as the "rich picture".

Mindmaps were constructed for the following areas: Technical issues, Economics, Education and Government. Figure 6 shows the five examples within the economics mindmap

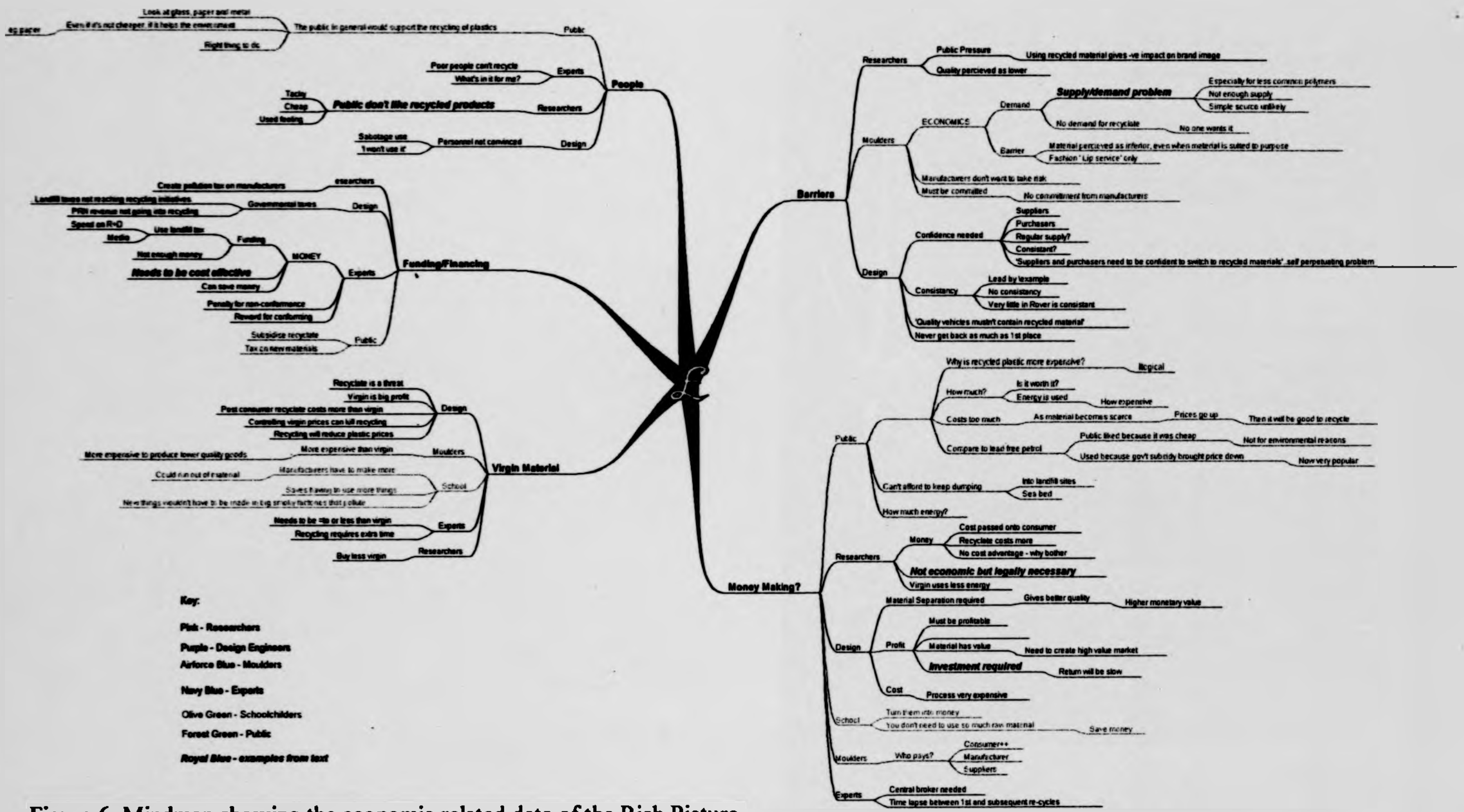


Figure 6 Mindmap showing the economic related data of the Rich Picture.

5.3 Processing of the rich picture

The creation of the mindmaps demonstrated the vast quantities of information gathered, the richness of which gave the opportunity to investigate several issues that had been brought to the surface. In particular issues dealing with technical, economic, education and government topics would appear time and again. Therefore, in order to maximise the possibilities of development of the recycling industry, the author decided to carry out separate SSM investigations in the areas of Technical issues, Economics, Education and Government.

5.4 Root Definition

Each of the four SSM investigations were analysed separately - each having a root definition, which were connected to each other through the rich picture that had been created of the Polymer Recycling System. Each root definition had similarities with but was not the same as the others. A full description and examples can be found in submissions 6 and 7 of the Engineering Doctorate Portfolio.

The root definition is an explanation of what the defined system that is being investigated, sets out to be, rather than what it does. By defining this, it focuses on who the customer of the situation is, who owns the system, who works within the system, what environmental constraints are placed upon the system and what the overall world-wide view of the system is. Collectively these areas of the root definition are known as CATWOE.

For the five worked examples shown in section 5.1, which were part of the economic aspect of the SSM analysis, the CATWOE and the root definition of the economic situation is shown overleaf.

C = CUSTOMER = *Beneficiaries* = The people, their community and industry

A = ACTORS = *Participants* = Government, Manufacturers, Design Engineers, Dismantlers, Customers, Reprocessors, Educators, Research Institutions, Insurance Companies. (As defined by EU Directive)

T = TRANSFORMATION = *Purposeful Action* = To ensure that post consumer recycled plastics are removed from the waste stream and used to the benefit of the community, whilst being able to make money. (In agreement with BPF Automotive Recycling Taskforce).

W = WELTANGSCHAUUNG = *World-wide View* = World-wide view of the system whereby all material is cost effectively recycled, as these would contribute to pollution reduction due to landfill avoidance and therefore the Environment is protected, whilst ensuring the longevity of the industry through cost effective and profit making systems. (In agreement with BPF Automotive Recycling Taskforce).

O = OWNER = *Authoritative Person(s)* = Government and Manufacturers (As per EU Directive)

E = ENVIRONMENT = *Environmental Constraints* = Within the UK environment, its legislation and valid specifications, imposed for the safe keeping of the people. (The remit of this research)

The CATWOE was used to create a root definition of the economic aspect of the Polymer Recycling System.

"A Government and Manufacturer owned system, jointly operated with Government, Manufacturers, Design Engineers, Dismantlers, Customers, Reprocessors, Educators, Motor Insurers and Research Institutions to ensure that the post consumer waste plastics are removed from the waste stream whilst being able to make money so that all the waste polymeric material is cost effectively recycled, as cost effective recycling operations would contribute to pollution reduction due to landfill avoidance and therefore the Environment is protected, whilst ensuring the longevity of the industry through cost effective and profit making systems, being the joint aim of Government and Manufacturers within the confines of the UK's environmental legislation and specifications, imposed for the safe keeping of the people".

The root definition is basically a specification of the ideal system. Once this specification is written, it is possible to create a model of this ideal system – which in SSM terms is known as the conceptual model.

5.5 Conceptual model

The conceptual model shows how the root definition can be achieved. It is often demonstrated as a flow diagram. The root definition and conceptual model moves the problem situation out of the real world system and looks at it within the idealistic model environment. This helps to clearly define the purpose of the idealised system, rather than what it does in the real world, which aids understanding of the situation.

The conceptual model is created from the root definition, which has been graphically created by the author, using a flow map. The conceptual model of the economic aspect of the SSM investigation is given in figure 7 as an example:

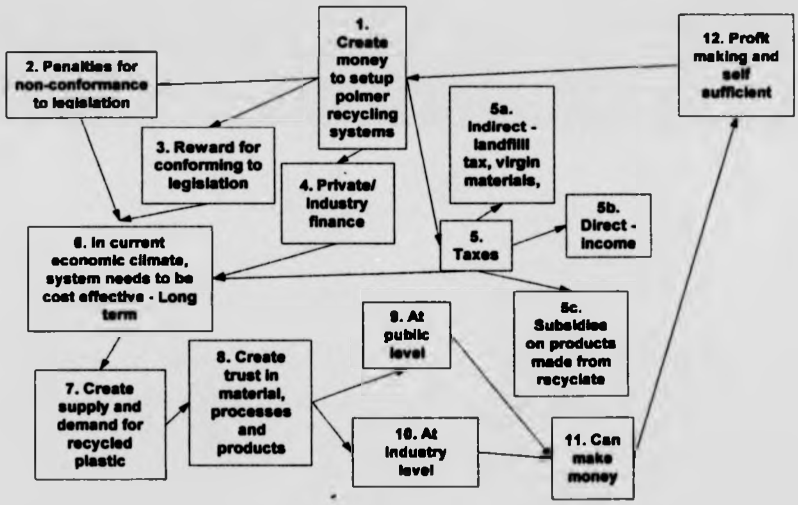


Figure 7 Conceptual Model of the Economic Aspect of the SSM Investigation

Source: Engineering Portfolio Submission 7

Once the conceptual model was created, a comparison was made between this and what is currently happening in the real world.

5.6 Comparison

The author elected to show the comparisons by creating a matrix to show these comparisons between the systems and the real world. This matrix has 9 columns and creates the rows by directly taking each issue of the conceptual model and carrying out the comparison. Each of the nine columns looks at a specific issue.

Column 1 - **Conceptual model** - taken directly from the conceptual flow chart.
Column 2 - **Exist or Not?** - Does the conceptual model exist in the real world?
Column 3 - **Real World** - what does exist in the real world?
Column 4 - **Performance Measures** - how to ensure that the move towards the ideal world is being achieved.
Column 5 - **Recommendations** - how to bridge the gap between the conceptual model and the real world.
Column 6 - **What stops this?** - What resource is lacking in order to achieve the conceptual model.
Column 7 - **Barriers** - What people and perception issues stand in the way of achieving the ideal situation.
Column 8 - **Who to influence?** - Who are the influential players in this particular part of the overall system?
Column 9 - **How?** - How can they make the changes in order to achieve and sustain the ideal world situation.

Therefore, for each point raised in the investigation, a nine-column matrix is created so that every idea for recommendation or change is subject to the same analysis. In this way the ideas are developed and presented in an easy to understand format.

An example of the economics matrix is shown in appendix 3 of this report. This matrix provides a comparison between current and possible future states for the five examples shown in section 6,1 and gives recommendations of how to achieve positive change.

5.7 Changes

The main themes of the recommendations created from the SSM analysis were then collated and are introduced in chapter six.

5.8 Action

The final stage of the SSM analysis was addressed initially in chapter eight and then further developed in chapters nine and ten.

6 Suggestions for improvement of the Polymer Recycling System

The suggestions that have come from the SSM investigation of the polymer recycling industry, have been brought together and the principal themes are described below. These give an overview of the work found in submission 8 of the Engineering Doctorate Portfolio.

6.1 Collection of spent plastic

Once the product reaches the end of its life, the customer needs to have some means that allows him or her to return the product to the supplier, or another responsible party, in a simple, quick and efficient manner, so that the product can be recycled. This system should be easy to use and preferably offer some incentive to ensure that the customer returns the spent product.

In the case of an end of life vehicle (ELV), the incentive could be given in the form of cash and/or a certificate of destruction. This would ensure the customer is not liable for road fund tax of the ELV.

6.2 Reprocessing

Ideally there would be few reprocessing stages, taking the minimum of time and money, reprocessing substantial volumes of spent plastic and being energy efficient. Therefore, large amounts of polymer need to be collected quickly and new systems would have to be developed.

Long term, it is conceivable that polymers will not need to be separated into generic families. Instead all plastic waste could be reprocessed together into a useful new polymeric product. Technologies that would allow this to occur are in existence already. However, they are expensive and not able to cope with the large volumes of polymeric material which are currently entering landfill sites across the country. This technical area needs to be further developed.

6.3 Logistics

Material would be transported from collection points to reprocessing plants. The number and length of journeys would be kept to a minimum, in order to keep fuel costs and environmental impact low. It is suggested that collection points for spent plastic should have plastic compactors or granulators so that large components can be reduced in size thereby maximising the density of transported material.

6.4 Legislation

The disposal targets quoted in the EU Directive for the major waste streams such as the automotive sector will mean that those held responsible for the disposal of spent products will need to work together with research institutions, educators, the media, the public and each other to ensure that legislation targets are met.

Collectively they will have to develop systems that can reprocess the high volumes of material in a cost effective manner and create a demand for the recycled plastic in order to develop a market for this material. Ultimately the legislation could give rise to a whole new industry that is profit making and job creating whilst serving to conserve raw materials and land.

There are some issues within the EU Directive that will need to be further developed by the UK government prior to the introduction of the UK legislation. These developments will have some bearing on how the industry is created. Issues such as specific responsibility apportionment, penalties of non-conformance and control measures will need to be monitored by industry so that they can develop strategies to ensure that they conform to the legislation.

6.5 Education

Education plays a large part in the SSM recommendations and is a key to achieving the long-term vision. Education is needed to raise awareness in industry about the myths and facts of polymer recycling. Education packages could be developed to promote design criteria for using recyclate and for designing for recycling.

Education packages could be developed for all the sectors to inform them of their role in the Polymer Recycling System. Coaching could be offered to develop people's ability to become proactive in their roles.

Schools, colleges and universities could run specific recycling courses covering technical and business issues. Engineering and Science courses could include the topic of recycling and its associated issues. A range of material, including games could be developed to promote polymer recycling education in a fun way.

6.6 Research and Development

Universities and other research institutions could carry out specific projects, in partnership with industry, to further develop recycling systems, processes and products to meet the needs of industry. This is currently happening in part[33], but could be far more prevalent in the future.

Novel solutions to the polymer recycling issues could also be created through national competitions (for example Tomorrow's World or Blue Peter television programmes could be used to reach vast audiences). These could be further developed by Research and Development centres.

6.7 Information collection and dissemination

Systems could be introduced to help the public to actively recycle plastics. Marketing ventures and PR work should be carried out to inform the public of what is being done and by whom, in creative ways. Various schemes could be developed to create novel ideas to improve the Polymer Recycling System for ELVs, specifically aimed at school children and the public. These would act to improve the recycling world and raise people's awareness, whilst developing their knowledge and commitment to making recycling of plastics work.

6.8 Perceptions

Information needs to be made readily available for people so that they can understand that there is a choice of recycling plastics and be shown how this is good for their society, families and themselves. Ultimately the aim would be to achieve a common message throughout the different sectors of society about recycled plastics and the views held by society would reflect its perception of reality.

6.9 Energy and Environmental benefits

Although this is a complex issue, there is evidence to show that polymer recycling can be carried out in an energy efficient manner, when compared to the use of virgin polymer[5]. In these instances, less hydrocarbon-based material would be used for creating new polymers. In addition, landfill sites would receive less polymeric waste. Therefore energy and raw material would be saved and space for landfill would also be saved.

6.10 Economics

In the long-term (5 to 10 years' time), the polymer recycling industry will need to be self-financing. This could be achieved through producing profits from reprocessing spent polymers and selling the product into a market (or series of markets) at competitive rates.

Further financial savings could be made by those responsible for the disposal of polymeric waste, for example in the motor industry, by:

a) avoiding landfill taxes,
b) avoiding penalties of non-conformance that would have to be paid if legislation is not met and
c) possibly gaining tax incentives for using recyclate instead of virgin plastic.

Industry would be able to fund further development work in order to innovate and maximise systems through partnerships with R&D institutions and universities. Thus the system would become self-funding.

In the short term, some moneys would have to be made available in order to aid industry, research institutions and universities as well as the development of any recycling centres that may be deemed necessary. In this way technology, processes and other tools that would aid the recycling industry could be created and developed.

The result of achieving the points raised in sections 6.1 to 6.10, could create a future where recycling takes place on a large scale and spent plastic from the ELV waste stream is removed. In this possible future, products from recycled plastics could be manufactured and sold in the market place, alongside other products from virgin plastic where the product could meet and surpass customer expectations.

The following chapter takes the themes presented in these sections a stage further and suggests how they could be achieved. The information is presented in matrix format and each suggestion is given a score rating for ranking purposes.

7 How the suggestions for improvement could be achieved

This chapter presents a number of suggestions that could help improve the current polymer recycling system. Using a matrix method of communication, it utilises the 10 issues described in chapter 6 to show how the suggestions would address and help to improve the current situation. Each suggestion, shown across the top of the matrix, is given a strong, medium or weak score of comparison against each of the 10 issues shown on the left-hand side of the matrix.

The suggestions given and the comparative scoring have been created by the author as a result of the SSM investigation and research in the automotive and polymer recycling field described in earlier chapters of this document. The suggestions presented here are intended to aid those affected by the pending introduction of ELV legislation in order to help shape the future of plastics recycling. They are not meant to be digested in their entirety or be prescriptive by nature. In addition, the importance placed on each recommendation has been given by the author in order to aid those involved in the task of implementation. Once again it is not meant to be prescriptive and should be re-visited during deployment. The deployment of these suggestions will be addressed in a future chapter of this document.

What needs to be achieved/how it could be achieved	Create definitive publication Design for Disassembly	Benchmark other collection systems	Develop new collection system eg certificate of destruction	Create definitive publication for Design for Recycling	Develop new sorting equipment	Develop recycling technique where sorting is not required
Collection of spent plastic	●	●	●	○	Δ	Δ
Reprocessing	○	○	Δ	●	●	●
Logistics	●	●	●	Δ	Δ	Δ
Legislation	●	●	●	●	●	●
Education	○	Δ	Δ	Δ	Δ	Δ
Research and Development	Δ	●	●	Δ	●	●
Information collection and dissemination	○	Δ	Δ	○	Δ	Δ
Perceptions	●	●	○	●	Δ	Δ
Energy and Environmental benefits	●	●	●	●	●	●
Economics	●	●	●	●	●	●
TOTAL	64	68	60	54	50	50

Key: ● Strong = 9 points

○ Medium = 3 points

Δ Weak = 1 point

What needs to be achieved/how it could be achieved	Material Granulated Prior to Transportation	Have Granulator on site at dismantlers	Create funding for granulator purchase	Create cleaning stations at dismantlers	Develop recycling system that needs no precleaning	Develop recycling plants and create new
Collection of spent plastic	●	●	●	●	○	Δ
Reprocessing	●	●	○	●	●	●
Logistics	●	●	●	○	Δ	Δ
Legislation	●	●	●	●	●	●
Education	○	○	Δ	○	○	Δ
Research and Development	Δ	Δ	Δ	Δ	●	○
Information collection and dissemination	Δ	Δ	○	Δ	○	Δ
Perceptions	○	○	○	○	●	●
Energy and Environmental benefits	●	●	○	○	●	●
Economics	●	●	●	●	●	●
TOTAL	62	62	50	50	64	52

What needs to be achieved/how it could be achieved	Increase use of recyclate in cars	Increase sales of recyclate to non car industry	Create generic specifications for recycled plastics	Create agent who would ensure supply and demand balances	Publicise successes to lead change (eg Nissan using post consumer recyclate)	Evaluate snapshot price of recycling vs cost of virgin manufacture
Collection of spent plastic	●	●	○	●	○	●
Reprocessing	●	●	●	●	○	●
Logistics	●	●	Δ	●	○	●
Legislation	●	●	●	●	●	●
Education	●	●	●	○	●	●
Research and Development	●	●	●	Δ	●	●
Information collection and dissemination	●	●	●	○	●	●
Perceptions	●	●	●	●	●	●
Energy and Environmental benefits	●	●	●	●	●	●
Economics	●	●	●	●	●	●
TOTAL	90	90	76	70	72	90

What needs to be achieved/how it could be achieved	Educate about benefits of recyclate using custom made education packages	Advertise positive message for recyclate	Raise public awareness through competitions	Develop chemical recycling and feedstock recovery systems that can cope with high volumes with low cost	Obtain project funding for novel techniques of recycling plastics	Create compatibiliser that ensures mixed plastic waste can be blended
Collection of spent plastic	△	△	△	△	○	●
Reprocessing	△	△	△	●	●	●
Logistics	△	△	△	△	○	○
Legislation	○	○	○	●	●	●
Education	●	●	○	○	○	○
Research and Development	○	△	○	●	●	●
Information collection and dissemiration	●	●	●	○	○	△
Perceptions	●	●	●	○	○	○
Energy and Environmental benefits	○	○	○	●	●	●
Economics	○	○	○	●	●	●
TOTAL	42	40	36	56	60	64

What needs to be achieved/how it could be achieved	Create education packages to show how to use recyclate	Create help desk to advise industry on how to use recyclate, where to obtain volumes etc	Help moulders use recyclate by demonstrating its use on test m/c	Ensure recyclate suppliers batch test to generic specification	Monitor material in service to ensure long-term fitness for purpose	Encourage public to take car to accredited dismantler by offering money
Collection of spent plastic	△	●	△	△	△	●
Reprocessing	△	●	●	●	△	△
Logistics	△	●	△	△	△	●
Legislation	○	●	●	△	△	●
Education	●	●	●	●	○	●
Research and Development	○	○	○	△	○	△
Information collection and dissemination	●	●	●	○	●	●
Perceptions	●	●	●	●	○	●
Energy and Environmental benefits	○	●	●	○	○	●
Economics	○	●	○	●	●	●
TOTAL	42	84	62	46	34	74

What needs to be achieved/how it could be achieved	Encourage public to take car to accredited dismantler by giving a certificate of destruction	Encourage dismantlers to collect end of life vehicles eg through subsidies?	Encourage car manufacturers to offer incentive to public to give ELV to dealerships	Define who is responsible for ELV disposal	Define how to implement responsibility	Set up monitoring system to ensure disposal targets are met
Collection of spent plastic	●	●	●	●	●	●
Reprocessing	Δ	Δ	Δ	●	●	○
Logistics	●	●	●	●	●	○
Legislation	●	●	●	●	●	●
Education	●	●	●	●	●	Δ
Research and Development	Δ	Δ	Δ	Δ	○	Δ
Information collection and dissemination	●	●	●	○	○	●
Perceptions	●	●	●	Δ	Δ	Δ
Energy and Environmental benefits	●	●	●	○	○	●
Economics	●	●	●	●	●	○
TOTAL	74	74	74	62	64	48

What needs to be achieved/how it could be achieved	Use monitoring system to demonstrate success	Have clear route for reporting any non-conformance to government/tax office	Create single united voice throughout industry - lead by example	Set up some organisation where all players are represented	Get media involved and create campaign with them	Create 'how to' videos (like those with John Cleese)
Collection of spent plastic	●	○	●	●	●	●
Reprocessing	●	○	●	●	●	●
Logistics	●	○	●	●	●	●
Legislation	●	●	●	●	○	○
Education	●	○	●	●	●	●
Research and Development	Δ	Δ	●	●	○	Δ
Information collection and dissemination	●	●	●	●	●	●
Perceptions	●	Δ	●	●	●	○
Energy and Environmental benefits	●	●	●	●	●	●
Economics	●	●	●	●	●	○
TOTAL	82	50	90	90	78	73

What needs to be achieved/how it could be achieved	Collect information from all the workings of the polymer recycling system	Create database from collected info. to help others solve similar issues	Use database for interrogation by help desk	Advise industry how to optimise usage of recyclate	Raise public profile of recycling indirectly through other initiatives ie kerbside collection	Track financial implications of recyclate usage versus virgin and publish trends / forecast etc
Collection of spent plastic	●	●	●	Δ	○	●
Reprocessing	●	●	●	●	○	●
Logistics	●	●	●	Δ	○	●
Legislation	●	●	●	●	○	●
Education	●	●	●	●	●	●
Research and Development	●	●	●	○	○	Δ
Information collection and dissemination	●	●	●	●	●	●
Perceptions	●	●	●	●	●	●
Energy and Environmental benefits	●	●	●	●	●	●
Economics	●	●	●	●	○	●
TOTAL	90	90	90	68	54	82

What needs to be achieved/how it could be achieved	Source funding routes and encourage industry/ partnerships to use	Develop working relationships with petro-chem companies (turning threat to opportunity for them)	Create body to co-ordinate funding/financing of development of polymer recycling system	Lobby Government to place tax on purchase of virgin polymer	Use tax to fund recycling initiatives
Collection of spent plastic	●	Δ	○	Δ	●
Reprocessing	●	●	○	●	●
Logistics	●	○	○	Δ	●
Legislation	●	○	○	●	○
Education	●	○	○	Δ	○
Research and Development	●	●	○	Δ	●
Information collection and dissemination	●	●	●	Δ	●
Perceptions	●	●	○	●	○
Energy and Environmental benefits	●	●	○	●	●
Economics	●	●	●	●	●
TOTAL	90	64	42	50	72

What needs to be achieved/how it could be achieved	Lobby Government to subsidise price of recyclate	Establish what quantities of recyclate are being used today in cars	Project future trends on usage of recyclate and monitor in future	Work with educators to create packages for schools	Work with educators to create packages for colleges/unis
Collection of spent plastic	Δ	Δ	●	Δ	Δ
Reprocessing	●	Δ	●	○	○
Logistics	Δ	Δ	●	Δ	Δ
Legislation	●	○	●	Δ	Δ
Education	Δ	○	●	●	●
Research and Development	Δ	●	●	Δ	○
Information collection and dissemination	Δ	●	●	●	●
Perceptions	●	●	●	●	●
Energy and Environmental benefits	●	○	●	○	○
Economics	●	○	●	Δ	Δ
TOTAL	50	42	90	38	40

What needs to be achieved/how it could be achieved	Work with educators to create packages for industry	Create waste minimisation game for educators etc	Encourage waste minimisation to raise environmental awareness and pr for recycling	Publicise how industry can make money through waste minimisation and recycling	Encourage Government bodies to provide funding for plastics recycling research projects	Encourage Industry to provide funding for plastics recycling research projects
Collection of spent plastic	●	○	○	○	○	○
Reprocessing	●	○	○	○	○	○
Logistics	●	○	○	Δ	○	○
Legislation	●	○	○	○	○	○
Education	●	○	●	●	○	○
Research and Development	○	○	Δ	○	●	●
Information collection and dissemination	●	●	●	●	●	●
Perceptions	●	●	●	●	○	○
Energy and Environmental benefits	●	○	●	○	●	●
Economics	●	○	●	●	○	○
TOTAL	84	42	58	52	48	48

What needs to be achieved/how it could be achieved	Investigate what components are forbidden from being made of recyclate	Where appropriate lobby Government and BSI etc to allow use of recyclate	Lead by example - provide conclusive evidence through demonstration of successes	Know when recycled plastic is inappropriate to use and ensure this is publicised
Collection of spent plastic	△	△	●	△
Reprocessing	○	●	●	●
Logistics	△	△	●	△
Legislation	●	●	●	○
Education	●	●	●	●
Research and Development	○	△	●	●
Information collection and dissemination	●	●	●	●
Perceptions	●	●	●	●
Energy and Environmental benefits	△	●	●	○
Economics	△	○	●	○
TOTAL	46	60	90	56

The scores provided within the matrix can be divided into three sections:

70-90 These suggestions have the highest scores, which means that they could have a major role in changing and developing the polymer recycling system.

For example '*Create database from collected info. to help others solve similar issues*' could be used to help industry help themselves by utilising a wealth of existing knowledge. This database of knowledge could help industry to bench mark best practice, learn from others' mistakes, and to gain contacts and expertise. Therefore the database could directly help to change and develop the polymer recycling industry.

The suggestions with high scores could be used directly to change the current situation and therefore author suggests that these should be developed first.

50-69 These suggestions are still considered to be important to the overall polymer recycling system but are not as significant as the first group. Therefore the author suggests that these could be developed as a second priority.

30-49 These suggestions are still useful and could play a role in the change mechanism of the polymer recycling system. However the links with those issues in chapter 6 are not as strong. Therefore these issues could be considered to be things that may help to change and develop the polymer recycling system. Many have a supportive role of other, higher priority suggestions shown within the matrix.

For example the suggestion to '*Monitor material in service to ensure long-term fitness for purpose*' only scored 34 but would clearly support most of the design and process suggestions. However most of the low scoring suggestions, including the example above, would not radically change the status quo individually and therefore they would be given the lowest priority.

7.1 Effecting change

This section describes how the author would achieve deployment of the suggestions presented in the matrices. The section is split into three sections; what the author would directly actualise, what actions she would take in areas outside her field of expertise and what could be done in areas outside the field of expertise for the vast majority of individuals.

7.1.1 The Author's Role

There are 68 suggestions provided in this chapter of this report. In order to implement the vast majority of these, the author recognises that she would have to retrain in a large number of different areas such as marketing, fund raising and creating a help desk. Although this is feasible, it would be time consuming and costly. Fortunately there are a large number of individuals who already possess many of these skills. Therefore the author will focus on her current field of expertise.

The author has a technical background, a working knowledge of polymer reprocessing and an in depth knowledge of the Polymer Recycling System with an emphasis on End of Life Vehicles. In addition, she has good leadership, facilitation and management skills, along with good communication and coaching skills. Therefore the author believes that she would be of optimum value as a leader and facilitator/coach within this change programme.

The author would bring together experts in the fields needed (for example marketing, polymer scientists etc.) and lead them to create teams that could implement specific suggestions.

The author would seek out individuals who have previous experience in fund raising and work with them to gain funding sources.

The author would also lobby parties such as Government to drive change where necessary (for example clarification of meaning within legislation).

7.1.2 Areas outside the author's expertise

The author recognises that there are many suggestions made within this chapter where she has insufficient expertise to implement the change herself. In these cases she would recruit people with specific knowledge. She would also recruit others to develop their previous knowledge through benchmarking other systems.

7.1.3 Areas where little knowledge is available

Some of the suggestions within this report require further research before they could be implemented. For example the reprocessing mixed plastic waste through feedstock recovery and the development of new processing techniques require more research and developmental work before they are viable. The author would therefore encourage researchers to develop these issues.

Overall the author believes that she would only be one of many people who would deploy the suggestions made in this report. However she recognises that her role could be vitally important in helping to create a framework and to implement these suggestions.

This chapter has provided the reader with scores for the 68 suggestions of how to develop the current polymer recycling system. These scores have been broken into 3 segments in order to give some order of implementation. The author has indicated what role she could adopt and has suggested what else could be achieved in order to effect change.

The next chapter investigates implementation techniques that are currently being used to deploy change at strategic and policy level. This information could be used to plan and develop an appropriate implementation technique that could aid successful deployment.

8 Current implementation techniques for strategic change

The full investigation into the techniques for implementation of the recommendations for improving the Polymer Recycling System can be found in submission nine of the Engineering Doctorate Portfolio. This chapter of the Executive Summary examines how strategic and policy issues are currently implemented and investigates two implementation techniques known as Management by Objectives (MbO) and Hoshin Kanri.

Currently there does not appear to be any one strategic implementation system used to action legislation in the UK. When legislation affecting industry is introduced in the UK it is often handed down to local government to administer and control, with industry being left to solve the question of how to achieve the legislative targets.

Government is known to make funding available that can be used by organisations to develop solutions that will help them to meet legislation. In the case of the ELV disposal legislation that is soon to be introduced in the UK, the DTI made available 1.8 million pounds[34]. This has been created to provide financial assistance for organisations to develop projects that will ultimately aid industry meet legislation targets[28]. This money has been allocated for seven projects, which will aid the development of systems for meeting the legislation. However it will not move the automotive industry forward to the point where all the 1.5 million vehicles which currently enter the UK waste stream per year, can be reprocessed to meet the pending legislation targets.

Quangos and committees are often set up, bringing together representatives from various sectors in order to address socio-political issues. However, these groups provide solutions to problem areas without creating an implementation framework to show how their recommendations can be achieved. Similarly, consensus tools such as the Delphi method have been used in the USA which also address the issues rather than provide methods of implementation.

In the case of the ELV directive, a committee was set up by the UK Government to discuss the issues arising. The committee members were largely taken from the Society of Motor

Manufacturers lobby group known as ACORD (Automotive Consortium on Recycling and Disposal)[35]. The consultation paper has recently been published and focuses on clarification of the directive terms and *what* systems could be operated by industry rather than *how* industry could meet the legal targets[36].

In looking for implementation methods for strategic change, the author found that there are two main methods that are used in industry, MbO and Hoshin Kanri. MbO is the most frequently used in the UK today and will be described in section 8.1. Hoshin Kanri was found to be more popular in Japanese culture but is slowly gaining popularity within western industry in alignment with Total Quality Management (TQM). Hoshin Kanri will be described in section 8.2 of this report.

8.1 Management By Objectives

This section describes the widely used implementation technique known as Management by Objectives (MbO).

The original development of MbO has been accredited to Peter Drucker[37] who realised that each member of an organisation had a role to play in order for the overall organisation strategy to be fulfilled. Therefore he recognised that every employee should be aligned to the overall company strategy.

MbO sets out to achieve the above by organising individual objectives towards the achievement of a common policy[38]. This is done by senior personnel in an organisation developing a strategy and then cascading it down through the organisational hierarchy, from senior personnel to middle management and then to junior management and team leaders and finally through to the non-managerial employees.

The intentions of MbO are positive, but there are many recognised issues associated with the use of this implementation strategy that compromise its effectiveness in the areas of communication and its being driven by results and outputs, rather than by the process.

8.1.1 Communication

The MbO approach to implementation begins by top-level management defining a company policy, strategy, mission or set of targets. The group that develops this is fairly likely to be unified in its chosen direction and able to communicate this amongst themselves. However, when this is cascaded through the hierarchy of the company, each group is likely to interpret it slightly differently, as each group has different needs and understanding of the business. This is compounded as the information travels further down the organisation and is either further distorted or misinterpreted or both[39].

Although there is now a movement towards placing more emphasis on the importance of the employees of a company, the actions of the senior management to improve communication and motivation are often in vain. This is, in part, due to the difference in culture and understanding of the various levels of the company, in which there would need to be a great deal of work to develop a common understanding prior to any major changes being seen.

There is also an issue surrounding the direction of communication. Clearly MbO operates using a top down approach, which is one way. This means that a manager develops the planning process without input from those affected, causing a lack of personnel empowerment and loss of information which may prove vital for a successful implementation.

One-way communication means that there is little room or encouragement for inter-departmental and cross-functional communication. Therefore, more barriers are created within the company and much information that could be useful to the successful implementation of the strategy is lost.

8.1.2 Focus on results

MbO often focuses on results rather than the process involved[37]. This means that targets are set without focus on how they will be met and this practice can sometimes lead to unrealistic targets being set with no means of achievement.

Through a focus on results, it is also possible to create a situation where performance gaps are only highlighted when it is too late to remedy them easily.

By focusing on results, one of the outcomes of using MbO is that employees can be unfairly assessed. This may occur if new targets have been set by management without an appropriate process being available for the employee to use to achieve those targets.

The employee is traditionally given one opportunity per year to be assessed on a formal basis in MbO, which is during their appraisal and even then the feedback from the employee is unlikely to be fed back up the hierarchical ladder in order to change the original strategy. Thus, any possibility of changing the process is likely to be lost.

8.1.3 Where MbO is used

Despite having several drawbacks, MbO is still the most commonly used implementation strategy used by western industry. Many automotive companies such as BMW and Vauxhall Motors Ltd[40] use MbO extensively.

So in summary, MbO is an implementation strategy commonly used by industry. It sets out to organise individual objectives towards the achievement of a common policy where each employee is aligned to the overall company strategy. The major shortfalls of MbO are that communication is often distorted or misinterpreted and that there is an emphasis on results rather than on process improvement.

These shortfalls were recognised in the 1960's and caused MbO to be developed further in Japan so that companies could implement their Total Quality Management (TQM) strategies.

8.2 Hoshin Kanri

Hoshin Kanri was originally developed in 1950, on a course that was sponsored by the Japan Association of Science and Technology. After this the methodology was used on an ad hoc basis. In the 1960's, Japanese industry began to recognise the shortfalls of MbO, which was widely used by them until this time. They therefore looked for alternative implementation methods and in 1962 the Bridgestone Tire Company adopted Hoshin Kanri and from there its popularity spread in Japan[41].

Western interest in Hoshin Kanri began in the 1980's as a result of the adoption of Total Quality Management (TQM) in many companies. As a result, it has been successfully adapted by several western companies under several guises, including AT&T (who called the system 'policy deployment'), Xerox (who named it 'managing for results'), Exxon Chemical (who called it goal deployment), the Rover Group (where it was known as 'policy deployment') and Hewlett-Packard (where it was named Hoshin planning)[38].

Translated Hoshin Kanri actually means:

- *HO* – method
- *SHIN* – shiny metal showing direction
- *KANRI* – planning

Therefore Hoshin Kanri can be translated as meaning 'methodology for setting strategic direction'[39].

Hoshin Kanri is a derivation of MbO that can be used as a strategic planning system and to implement an existing plan. Its principles are centred on companies knowing what their customers will want and need in five to ten year's time and on understanding how the company can surpass the customers' expectations[41].

8.2.1 How does Hoshin Kanri work?

Hoshin Kanri works with the principle that the implementation of a vision or strategy should be planned by those who are going to execute it, rather than a separate group of people[42]. Therefore the top level of an organisation will put together a vision and send it through the organisation for comment. The Japanese use of Hoshin Kanri means that each member is asked to comment on 'If this were the vision, what would you do?' whereas the more western approach may entail asking what is right or wrong about the vision. Either way this information is passed back up for checking of understanding by the employees and appropriateness of the vision to achievement of the desired outcomes[43].

Once the 5-10 year vision is agreed and set, the organisation breaks this down into a series of step goals of say 1-2 years in duration which take the organisation towards the 5-10 year vision. Within these step goals each individual member of the organisation decides how they can help the company achieve the goal and they communicate this so that they can become aligned with others in the organisation. Please see figure 8. for a graphical representation of Hoshin Kanri.

Figure 8. Hoshin Kanri Model – adapted from Hoshin Planning – The Development Approach, King, B. 1989.

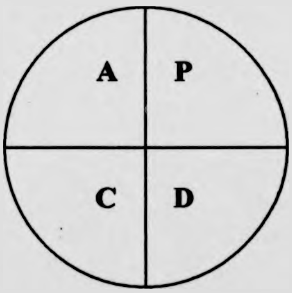
The use of Hoshin Kanri as an implementation technique gives individuals the responsibility for setting their own goals and objectives, in line with the long-term company vision. It is also process focused that is to say it looks at the root causes of issues rather than just the symptoms[43].

In terms of assessment and control, individuals, teams and managers are empowered to set their own targets of achievement. Once again these are process focused and diagnose the progress towards the vision and the step goal. Evaluation targets are set on a monthly basis.

In short, Hoshin Kanri can be described as an implementation methodology that has adopted the Deming style 'Plan-Do-Check-Act' (PDCA) methodology. This has been modified for the purposes of Hoshin Kanri and become known as the FAIR model. See figure 9.

Focus: Review corporate strategy and agree vital few

Alignment: Translate vital few and develop cross-functionality



Responsiveness: Monitor progress both daily and periodically

Integration: Align to daily management and projects

Figure 9. A comparison between Deming's PDCA and the FAIR model of Hoshin Kanri Source: Witcher, B. and Butterworth, R. 'What is Hoshin Kanri? A Review', Economic and Social Research Council, June 1999, UK[44].

Hoshin Kanri appears to be an excellent tool for devising and implementing plans, as it encourages every individual within an organisation to work within a continuously improving organisation with long term targets, focusing on process rather than traditional MbO style of dealing with symptoms as they arise. The measures are realistic as they are determined by those people responsible for meeting them and there is communication carried out both up and down the organisation, rather than only top down as in MbO.

However there are issues that may arise when using Hoshin Kanri in an environment that is unused to such systems and where MbO has been in operation for many years. In this case there may be some work needed to create an open and trusting environment in line with Deming's work[14], prior to the adoption of Hoshin Kanri.

If there is conflict within the organisation regarding a part of the plan, then conflict resolution can be found using a consensus building technique. This allows conflict to be viewed as a potential benefit[45]. Rather than focusing on the rights and wrongs of a situation it should be possible to focus on the data behind the beliefs people are operating[42] and use this to develop methods to overcome possible areas of conflict.

The philosophy of Hoshin Kanri is in harmony with the overall research carried out by the author. In particular, the principles of Soft Systems Methodology (SSM) as described in detail in submission six of the Engineering Doctorate Portfolio, promote the idea of participation in the execution of the plan of change by those affected by the system. Therefore Hoshin Kanri has been selected as an appropriate technique for implementing the recommendations for change to the Polymer Recycling System in the UK. The next chapter describes the use of Hoshin Kanri to deploy the changes developed using SSM.

9 The Use of Hoshin Kanri to Deploy Improvement Recommendations for the Polymer Recycling System

This chapter describes the use of Hoshin Kanri to implement the recommendations described in chapter 7 of this document. Further details can be found in submission 10 of the Engineering Doctorate Portfolio.

Within this chapter, a strategic mission is devised for the Polymer Recycling System, from which a five year plan is created. This plan is further developed and attention is paid to auditing the changes made following the Hoshin Kanri protocol.

9.1 The strategic vision

Initially the author has written a strategic vision for the Polymer Recycling System in order that the recommendations are focused into a set of achievable goals that can be written as the following[iv]:

To ensure that industry meets and surpasses legislation targets of ELV disposal, solutions are to be developed that will enable industry to benefit from plastic recycling, providing the capacity to use, process and produce products manufactured of recycled polymers and to make money from doing so. Ultimately, customers will have information and choices available, allowing them to readily purchase the product, derive pleasure using it and are delighted with the performance of the product.

In order to achieve the strategic aim, many issues need to be addressed within the areas of technology, education, economics and public relations. These have been introduced in chapters 6 and 7 and the main themes are now developed. Overall if these issues are addressed and success is achieved in these areas then the vision will be satisfied.

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iv. [iv] This strategic vision is derived from the SSM root definitions found in submission seven of the Engineering Doctorate Portfolio.

9.2 The 5 year strategic plan

The following is a list of deliverables that the Polymer Recycling System could achieve:

- New recycling technologies and processes in the field of:
    - Materials: Thermoplastic polymers, Thermoset polymers, Mixed Plastic Waste, Chemical recycling and Energy Recovery.
    - Industry standards for recycled materials.
    - Logistics – Transportation, Energy usage.
    - Dismantling.
    - Design.
- Education packages for industry, academia and public. Publications.
- Patents.
- Advisory centre for industry.
- Identification of new market opportunities for use of recyclate.
- Recycling knowledge base.

The overall vision of the Polymer Recycling System would require a time-scale of 5 years to achieve. This is in harmony with the timed disposal targets set in the EU Directive of 2007 and 2015. If the implementation plan is in full operation by the year 2007 then it will help industry meet legislative targets.

In order to implement the strategic vision using Hoshin Kanri, a series of plans need to be developed by the team. The initial 5-year strategic vision needs to be broken into a number of plans for each of the sections of the recommendations. There needs to be measurement criteria set to gauge the success of the various parts of the plan. It is important that the measurement criteria are created, developed and agreed by those who are actually doing each part of the plan so that a true reflection of the work output is given. In addition there needs to be a monthly and yearly diagnosis to ensure that progress is made.

9.3 The 3 phases of implementation

In five years from initial set-up, the author envisages that all the issues in 9.2 could be developed and in use. There could be 3 phases within the five year plan; initial start-up (six months), phase two (six months to four years) and phase three (year four to five). Within these phases the information from the matrices presented in chapter 7 could be used to prioritise the implementation of the suggestions.

Phase 1 6 Months from start

In the first six months the author envisages that the following will be developed and implemented:

- Create and promote profile, using marketing strategies such as brochures, seminars, lectures, company visits, surveys, advertising, trade magazine articles etc.
- Re-educate industry, education establishments and the public through modules, short courses, seminars and site visits.
- Researchers to either set up and develop new projects or continue their research.
- Begin building up relationships and partnerships with industry.
- Focus on the highest scoring issues described within the matrices of chapter 7

Phase 2 6 months to 4 Years

In phase 2, the author envisages that the following will be developed and implemented:

- Relationships and partnerships established.
- Realignment of education in line with industrial requirements and new technology.
- Break through technology and processes coming to fruition.
- New projects identified, funding secured and additional researchers recruited (minimum 1 per year).
- Advisory centre available to industry as consultancy/knowledge based system.
- Starting to become self-funding through patents, new technology and processes, publications, courses and consultancy.
- Focus on those suggestions with the medium scoring issues described within the matrices of chapter 7.

Phase 3 4 to 5 Years

In phase 3 the author envisages that the Polymer Recycling System will be:

- Renowned and self-funding.
- Flexible to meet future needs of industry and Europe in general.
- Continuing to identify and develop new technologies and processes.
- Managing partnerships and developing new.
- Continuing the success of self-funding educational courses and advisory centre.
- Focusing on the lower scoring issues described within the matrices of chapter 7

9.4 Yearly Plans

There would be yearly plans developed within phases 2 and 3, in each of the areas being developed. These yearly plans would be created by those within the Polymer Recycling System.

9.5 Execution

Each of the plans will be developed by those within the Polymer Recycling System, so that they are responsible for the progress of individual projects, know what role they have to play and have set their own criteria for measuring their success and the success of that project. The members could achieve this by creating a detailed plan of how they intend to execute the overall vision. This would include agreement of what needs to be done and apportioning responsibility for specific tasks. In addition they would define how they will report what they are doing on a monthly basis so that problems are swiftly dealt with and any successes can be communicated throughout.

9.6 Audit

The members would then begin to activate the projects and feedback on a monthly basis. The feedback would be fed through the organisation on an annual basis so that the performance could be measured against the intermediate plans and also the overall strategic vision.

The detail would be developed by the members of the Polymer Recycling System, using Hoshin Kanri.

9.7 Beneficiaries

The aim would be to assist sectors of the UK society to meet legislation, create new industry and jobs, create new research projects, create new education packages, help to keep plastic from our landfill sites and use spent plastic instead of new material which is produced from the non-renewable source - crude oil. The sectors to be assisted are:

- Industry
- Public
- Research establishments
- Schools, colleges and universities

9.8 Pre-requisites

As a pre-requisite to implementation using Hoshin Kanri, those involved will be given the opportunity to benefit from some development training which is taken from King, B. (1989) and is shown in figure 10.

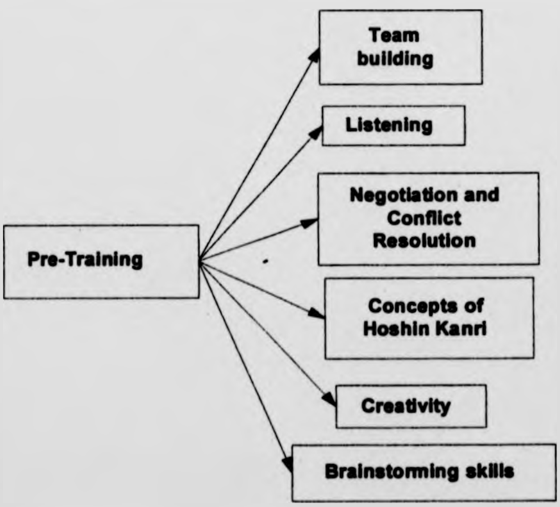

Figure 10.– Pre-training prior to the deployment of Hoshin Kanri.

It is thought that these skills will give the basis on which to develop a creative and realistic plan of deployment, whilst being able to address any conflicts of interest that may arise.

The next chapter introduces the idea of one central body, created using Hoshin Kanri and capable of organising and achieving the recommendations, to improve the Polymer Recycling System.

10 The Polymer Recycling Hub

Currently there is not a recycling infrastructure capable of coping with high quantities of polymeric material. Indeed, the general view from industrial specialists is that it will not be possible to meet legislation. There is, as yet, no clear vision of how things could be done and there is much negativity, within industry, towards the impending legislation. Many views appear to be based on what is happening today or what used to be true – not what could be possible tomorrow. However, there is some movement, in isolated pockets, towards driving the industry forward, although there is no major co-ordinated plan to seize the situation and make it an opportunity[v].

There are so many different strands of the Polymer Recycling System that it would be appropriate to create a single body to represent all the key players of the system. This single body would be able to develop the education packages, provide information dissemination for industry, information for the public, promote the material and co-ordinate any funding / research projects. It would also be able to monitor and publish the results of industrial practice in order to gauge the success of the recycling industry. This body has been given the name the Polymer Recycling Hub or the "Hub" for short.

The Hub gives a clear direction to move forward and needs to be driven by a motivated leader together with a united team. The development of this team, its commitment and unified direction is of the utmost importance to the success of the vision. Every team member would need to understand the overall aim of the vision, be committed to this and be given the opportunity to enjoy the overall process of developing their particular area in the manner best suited to them. In this way, there would be great potential for the team to develop beyond this vision, and take pleasure from what they are doing. A graphical representation of the Hub is shown in figure 11.

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v. [v] Groups such as The CARE Group and BPF Automotive Recycling Taskforce are leading projects to further the Polymer Recycling System from ELVs in the UK.

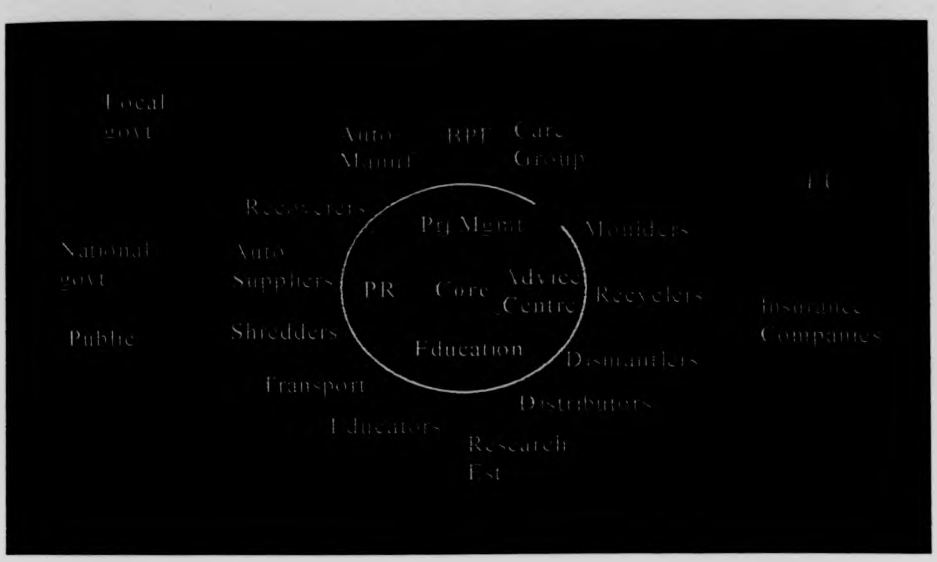

Figure 11. Graphical representation of the Polymer Recycling Hub

The concept of working within united teams is not new. Coaching[46] and NLP specialists[45] have developed models of excellence, highlighting means of developing such qualities within groups of disparate people, which is also in harmony with the work of Deming[14] and Covey[47].

10.1 How the Polymer Recycling Hub will overcome current issues

The overall aim of the Hub is to create a process for actively developing an infrastructure capable of meeting and surpassing legislative targets for the disposal of spent plastics from ELVs. The Hub is not a discussion group. It would be an action driven strategic tool that develops the recycling system for ELV plastics in the UK.

10.2 Who would be involved in the new vision

For ELV disposal, the automotive industry would be directly involved in the new vision and in particular, those 'economic operators' outlined by the EU directive, being producers, distributors, collectors, motor vehicle insurance companies, dismantlers, shredders, recoverers, recyclers and other treatment operators. In addition, the author envisages that education establishments, research institutions, the public, local and national government and the media would be involved.

Figure 11 shows how it is expected that some of the members are likely to take on a funding type role. These are shown on the outside of the outer circle of the diagram. Those members who are likely to take on a more direct role are shown within the outer circle. In addition there could be a small core team of people facilitating and co-ordinating the projects. These are shown in the inner 'core' circle.

10.3 Government

Government is already heavily involved by creating waste disposal legislation and although this states that the responsibility of ELV disposal lies with the automotive industry, it is already starting to provide financial support to develop the infrastructure[48]. This will ultimately help to ensure that the legislation targets are met.

Governmental departments such as the DTI and the DETR will be involved in providing financial and other assistance to help create the recycling system. National government could provide support for local government to help it in its role.

Local government will be involved in local initiatives to set up new companies, and could play a major role in promoting the plastics recycling concept to the public through advancement of the concept of recycling through funding of local companies and public relations exercises.

10.4 Industry

Industry will be directly involved. Car manufacturers and their suppliers, dismantlers, shredders, recoverers and recyclers, in the case of the ELV legislation, will each have some responsibility apportioned to them for the disposal of ELVs. It is therefore in their best interest to ensure that cars are easy to dismantle, since this means less time to strip the car down and less time equates to less cost.

Reprocessing of large volumes of polymers, including the collection, dismantling and transportation is likely to create new companies and therefore new jobs throughout the UK.

Ideally the virgin polymer manufacturers would be involved and work in partnership with the new industry, product manufacturers and the other industrial parties involved. This would help to create an environment in which the people who know the most about polymers (the creators of them) are actively working to solve some of the issues associated with their products. Often these polymer manufacturers are large and influential corporations that have the knowledge, finance and resource available to develop new ideas and systems and help industry to solve the problems surrounding recycling polymers. They could turn a threat (recyclate often being in direct competition with virgin plastic) into a potential opportunity that may provide new profit making possibilities for them. Some virgin polymer manufacturers such as Elf Autochem are becoming involved in polymer recycling initiatives [49].

Within industry, each of the sectors highlighted in the EU directive will be able to have its own role to play. These will be described in the following subsections.

10.4.1 Producers

The vehicle and component manufacturers will be able to reuse the reprocessed ELV polymeric material in the production of new vehicles. This would create the market for the recyclate and provide demonstration products for other industries to gain confidence in recyclate. This has not yet been achieved by industry, except in isolated cases such as battery cases[7].

The producers could also work with all other parties to help develop and maximise processes that would ensure recycling of ELV polymeric material is efficient and able to cope with the large volumes involved.

Producers could work with research institutions to develop appropriate research projects and with educators to develop appropriate education packages for industry, the public, and schools/colleges.

Producers could ensure that their design engineers design for recycling and use the recyclate to produce their components.

From literature and active research, the author has found that there is some talk of achieving all the above although in reality very little is currently being achieved in a co-ordinated manner.

10.4.2 Distributors and Collectors

Distributors could collect faulty parts from garages for reprocessing and work with collectors, dismantlers and recoverers to maximise transportation, through the appropriate use of granulators, containers, vehicles and logistics computer systems. Research shows that this is not currently achieved in a high volume and co-ordinated manner in the UK. However with careful logistics control this could be achieved, as is currently happening in New South Wales and South Australia, in the case of Holden's damaged parts[50].

Although this is not strictly covered under the EU directive, as the damaged parts are not generally coming from ELVs, they would still be destined for landfill sites throughout the UK and therefore add to the waste stream. Also, the system could be co-ordinated with other collection methods of plastics from ELVs.

10.4.3 Dismantlers and Recoverers

Dismantling and Recovery sectors could develop systems that are capable of removing plastic from ELVs, sort them into generic plastic types or compatible materials, granulate (if appropriate) and put the material in containers ready for the collectors and distributors. Active research has shown that this is currently carried out manually, if at all.

Dismantlers and Recoverers could collectively work with research institutions to create new processes and develop existing ones. This has begun to happen at Brighton University[10], but much more could be achieved.

There may be an issue with the economies of scale, as there are 4-5,000 dismantlers in the UK alone (of which approximately 1250 are registered)[1]. This means that it would be difficult for each individual dismantler to work with car companies, suppliers etc. However, they could form a consortium, operate collectively through the Motor Vehicle Dismantler's Association (MVDA) or work with their local shredders, who in turn could liaise with other sectors of the industry.

It could be argued that the ELV directive is a great threat to the dismantlers and recoverers, since they currently recycle profitable material (metal) and discard the rest. However, it could be possible for dismantlers and recoverers to create opportunity for their industry, through partnerships and the development of the items mentioned in the first paragraph of this section.

10.4.4 Shredders

Shredding companies could work with dismantlers, recoverers, collectors, distributors and research institutions to help develop systems that would improve the collection and sorting of polymeric materials. They could also co-ordinate the work of the shredders as described in 10.4.3.

Shredders could also work with the research institutions to develop technologies capable of using shredder residue – material left on a vehicle once the metal is removed. This is happening at Brighton University but could be expanded upon in the future.

10.4.5 Recyclers and other treatment operators

Recyclers and treatment operators could work collectively with virgin polymer manufacturers and research institutions to develop systems capable of reprocessing the high volumes of plastics in a cost-effective manner.

Specific areas that could be developed are feedstock recovery plants and compatiblisers that could be mixed with all spent plastic that would enable them to be mechanically reprocessed together without separation.

10.4.6 Motor Vehicle Insurance Companies

Motor vehicle insurance companies are included in the EU Directive as being partially responsible for the disposal of ELVs. Therefore they could help raise funds that would finance the research and development projects, providing part of the finance along with other sectors.

10.5 Educators

Educators, including chartered engineering institutions, could be involved in raising public awareness and informing and coaching schoolchildren, college students, the public, design engineers, moulders, sales people, media and any other group that would come into contact with the polymer recycling industry. Although this may be happening in isolated pockets, it is not occurring in a co-ordinated manner.

10.6 Researchers

Researchers would be involved in maximising reprocessing systems already in existence and would work to provide new techniques and systems for recycling. They would work with industry to ensure that projects are developed for application and with educators to disseminate information. Although some institutions are working with industry to this end, there are many other opportunities for research establishments and industry to work together.

10.7 The Public

The public could be given the opportunity to benefit from the systems created by government and industry in order to reprocess the spent plastic, through environmental implications, quality of life, possible financial savings and improved product quality, by purchasing products containing recycled plastic.

10.8 The Media

The media could be involved at a national and local level. They could promote all the work that the other parties have developed, disseminate information and help to educate the public. They could also run competitions for novel ideas that could be developed further with the winners and the research institutions.

10.9 Overview of the Hub

The Hub would need a leader who could facilitate the system and focus the direction the new vision takes. This leader would need to be backed up by a small team of focused people who could provide support and liaise between them and the other representatives who would make up the 'Hub' of the organisation.

These representatives, as shown in figure 11, would come together and would bring specific issues that are important to the group they represent. Together in partnership the Hub would develop strategies for tackling these issues within the polymer recycling industry. As each strategy is developed, the responsibility for action would be apportioned; timing and control measures would be agreed by all those active in the issue.

It is envisaged that the Hub would physically meet in the initial stage to develop strategies for the successful implementation of the different aspects of the Hub. For example, the technical projects would be discussed and prioritised to decide which of the many projects would need to take priority. Then decisions could be made about what resource would be needed and whether it would be available from within the Hub members, or whether outside help would be required. The Hub members could then decide how best to bring in outside help – whether to offer Hub membership or simply buy in the resource. This would be done for each of the projects and is likely to take 4-6 weeks full-time work from all the Hub members.

After the development of the strategies and apportioning of responsibility, the author envisages that other means of communication could be used – such as video conferencing, webcams, e-mail and the telephone to maintain a high level of interaction without the disruption of constant meetings. Thus, the representatives could remain in their original environment where they could stay close to what is happening in their organisation and also oversee any work to which their organisation is committed.

The Hub would be an independent body that would be initially funded by local, national and European government, insurance companies and indirectly by the public (as shown on the outside of the Hub circles in 11). It would aim to be fully supported by industry after a period of 5-10 years, to ensure that it provides profit making innovative solutions. Some money would be available for funding projects that are carried out by members and for non-members who are brought in to do specific jobs such as advertising agencies and legal advisors.

The Hub would have moneys available for specific research projects that industry require and this money would be apportioned to the appropriate R&D establishment, as agreed by the Hub collectively and in-line with other funding bodies, such as the EPSRC. This money would be made available through government schemes (local, national and European) and industrial partnerships.

All information that is created and developed from the Hub would be made available to all members within the Hub and used to develop education and advisory packages for schools, public, colleges, universities and industry.

In addition to the above, the information from the Hub would be collated and placed into a knowledge database which could be used to help industry solve specific issues as they arise. Overall, the Polymer Recycling Hub would be created to provide all sectors of society with potential win/win situations. Any member or group within society, regardless of which sector they represent, could ask for specific help or advice. This information could then be fed into the Hub's database of knowledge, where it could be further used to help others, should a similar issue arise.

10.10 The Hub's work environment

The Hub would be created with a clear sense of purpose. The individuals would collectively develop the strategies for achieving its goals and would therefore own the strategy. They would be committed to the strategy, since they developed it and feel responsible for achieving its success, as the success of the Hub equates in part at least, to the success of themselves.

The team that develops the Hub would form its own dynamic. With care, an environment of openness, support and trust would be likely to develop, particularly if the leader helps to facilitate this.

10.11 What resource is needed?

Little resource, including small capital expenditure, is needed to create and run the Hub. Items for consideration include premises, communication equipment, wages of personnel and pool cars. The major cost would be the wages of the individuals. Full details can be found in submission ten of the Engineering Doctorate Portfolio.

10.12 Deliverables

The Hub would be expected to deliver a variety of solutions so that industry and society in general will benefit. The specific areas where the Hub would deliver solutions to today's issues are: Technology, Education, Public Relations and advice. Figure 12 shows the Hub's deliverables on page 91 of this report.

10.12.1 Technology

Projects would be set up in the research institutions that are best suited to solve specific industrial problems relating to plastics recycling. Industry would come to the Hub with its issue and the Hub would put this out to its members. The R&D members that have the appropriate resources would be invited to make a proposal and the Hub would choose which is most suited. Alternatively, it may decide to select a combination of Research Institutions to work collectively, using criteria that would be developed by the Hub in the initial stages.

Other long-term projects could be used to develop new and novel solutions to overcome the recycling issues. These would be developed by the group as a whole and would be able to use the breadth of expertise available both within the Hub and from the organisations that the Hub members represent. Indeed, the major benefit of the Hub is the wealth of knowledge and resources available to its members. Industry and R&D institutions could work together to deliver real life solutions.

The author envisages that this collection of resource would lead to new ways of overcoming so many of the barriers to the Polymer Recycling System's success. For example, if the petro-chemical companies realised the opportunity and benefits for them they could use their wealth of knowledge about polymer manufacture and development. They would benefit from being a part of the Hub by turning recycling of plastics into an opportunity for them, on a PR level, a market level and maybe even a technology level.

The author envisages that the Hub would work on the following projects:

- Reprocessing mixed and dirty plastic into new and useful plastic material – by mechanical, chemical or feedstock recovery methods.
- Removing the plastic material from the spent product in a fast reliable and cheap method, inline with health & safety, and pollution regulations.
- Developing systems capable of continuously reprocessing plastic waste in such a way that the end product has constant and repeatable properties, regardless of the state in which it is fed into the reprocessing plant.

- Creating specifications for recyclate and giving these to the PR section of the Hub to help raise awareness of the material which would be accepted and used by industry.
- Creating design guidelines for industry using recycled plastics in their new products.

It is expected that the Hub would set up specific R&D projects and would define their own measures of success, notable milestones etc. The project groups would be given the opportunity to disseminate their findings to the rest of the Hub at regular intervals.

Overall the Hub would be most likely to have all the skills and resource needed to develop these project areas. However if there were a gap in the resource needed then it would be most likely that someone within the Hub would know where they could find a solution. The solution could either be contracted in or preferably, the organisation providing the solution could be invited to join the Hub.

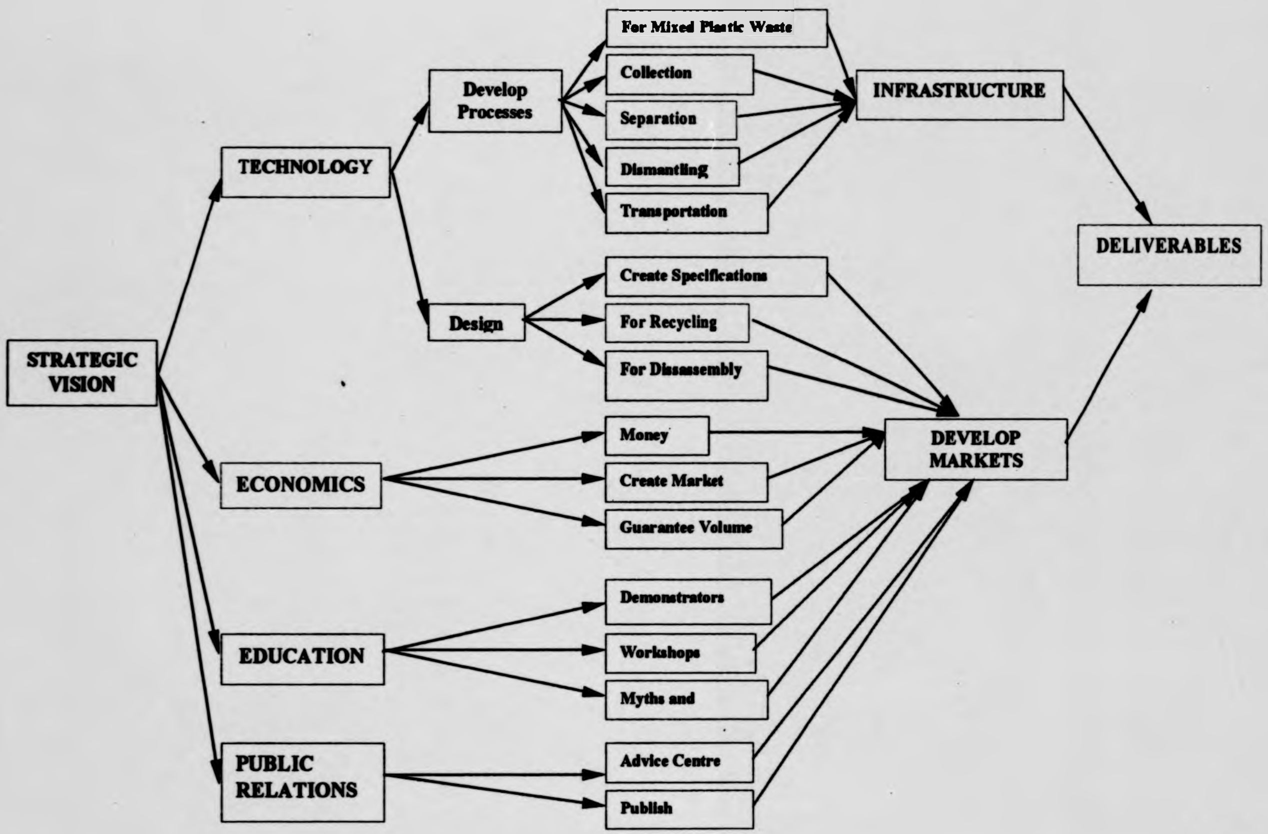

Figure 12. Deliverables of the Polymer Recycling System

10.12.2 Education

Members of the BPF, SMMT and the CARE group agree that education is a massive area that needs considerable work. Education is the key to changing people's perception of recycled plastics by dispelling the myths and legends that surround this issue. Education of plastics recycling needs to be carried out at all levels of society – schools, colleges, universities, industry (design engineers, material buyers, plastic moulders, specification writers of companies and BS/ISO) and the public. The overall message must be the same – that plastics recycling is achievable and if the material is used in the right way then its properties could be exploited and money could be made. Of course, each sector of the market would need different information and different levels of detail. Therefore it is perceived that the general educational packages would cover topics such as:

Schools: Plastic –	What it is and what is used to make it (hydro-carbon from the earth). Why it is important to conserve this as much as possible. How we could conserve this and how each and every one of us could help to do this.
Colleges: Plastic-	What it is in more detail, what it's used to produce and why it is used over and above other materials. Describing the different forms of plastic and its recyclate. Issues that have yet to be overcome. What the ideal world would look like and how individuals could help both at home and in their future working life society to move towards the ideal scenario.
Universities:	Whole university degrees could be designed to cover recycling in general and specifically plastics recycling. The course could cover waste streams, their constituents, methods of material separation, ways of overcoming the need to separate materials, design with recyclate, design for recycling and dismantling at the end of the products life, materials and specifically plastics reprocessing systems, methods of improving these, the economics of recycling, life cycle analysis (energy balance equations), market issues (supply/demand issues), legislation and environmental issues.
Industry:	A lot of the areas mentioned above in the university degree could be tailor made for industry, although the degree itself would need far more

information than industrial managers would necessarily need. However, specific industrial education packages could be put together covering topics such as design capabilities and limitations of the recycled plastic, designing for products to be recycled at the end of their life, how to use recycled plastics in the best possible way, legislation – what could and could not be done and what the penalties would be for not doing them, who could help with what.

Public: What plastics recycling is all about and what does it mean to them. Why should they bother to support an emerging recycling industry. What they stand to gain. How would they know what products have recyclate in them? How would they know what to buy – and what to avoid? When is recycled plastic better than normal plastics? How they could help.

The educational group within the Hub would work alongside and in many instances be one and the same people who are involved in the technical aspects of the Hub. They would need to develop educational packages that are interesting and informative at the same time and, ideally, fun to use. The author perceives that there would be a lot of innovative ideas put into action when creating and delivering these packages.

10.12.3 Public Relations (PR)

In close partnership with the education packages detailed in 10.12.2, the PR activities would serve to raise the awareness of the Hub itself, the work that it is doing and most importantly recycled plastics. It is likely that this would occur in many different ways and may include some or all of the following, plus others that would be developed by the Hub and haven't been considered by the author:

- Conferences for industry, educators, pressure groups and other interested parties. These would serve to raise awareness of the Hub and its raison d'être, as well as give the Hub the opportunity to disseminate information from its work.

- Advertising - aimed at the public in order to raise their awareness about recycling and recycled products.
- Leaflets and brochures - aimed at industry – raising awareness of the need to recycle, how companies could recycle and where they could get help and advice.
- Competitions – aimed at children and young adults, looking to raise awareness of recycling and help to solve issues using novel ideas.
- Enlisting the support of media – programmes such as Blue Peter for children, certain Radio 4 programmes and Radio 1 DJs to inform adults. Local TV station news bulletins, Local and National papers for all.
- The Internet – create web site with exciting and professional pages, going from an overview through to great detail.

The overall aim of the PR section of the Hub would be to raise awareness and disseminate information to those who are interested. In addition to this, the Hub would also create an advice centre where all sectors of society could call in, either by phone, email/web or, if deemed necessary, in person.

10.12.4 Advice Centre

The advice centre would be set up by the Hub to provide advice on all aspects of polymer recycling. Any question related to this could be asked. It would have a database of previously answered issues, current issues that are being investigated and the names of those who are responsible. This would help to answer regular questions quickly, via an Internet Website, Email or telephone. A system would be devised to deal appropriately with those in-depth questions that have not been previously entered into the database. In addition, the knowledge accumulated from all the different sectors that are involved in the polymeric recycling industry could be made readily available to all interested parties. This information database would be regularly updated to reflect the depth and richness of information from all the participants.

The advice centre could also have to provide industry and education with tailor-made packages to help them become better informed, and would even offer specific help for particular issues, if needed, including training/coaching and advising. This could be for any type of issue associated with the recycling of polymers, or minimising of polymeric waste.

It is likely that replies would be given free of charge to any member of the Hub and would cost a minimum amount for other organisations not part of the Hub. The detailed working of this advice centre would be created in the first phase of the Hub.

10.13 Measurement of success

Measurement of success would depend on which particular part of the Hub is being talked about. In line with Deming's philosophy[14], the teams that are setting up the specific projects could be responsible for determining the most realistic method of measuring the success of that project. The project would be their responsibility and they would know better than anyone what criteria would be most fitting for that work. The measurement of success is vitally important so that all the members know what they have achieved and when they have achieved success and each project measurement criteria could be agreed in phase 1 of the Hub. In subsequent projects the measurement of success would be defined at the same time as the project outline.

The measurement of the Hub's success would be complete when the plastics recycling targets laid out in legislation are met and surpassed, when products are freely manufactured using recycled plastics and when they are actively purchased alongside, or in preference to, products manufactured from virgin plastic.

Some indicator of progress towards the above goals would be needed and in order to achieve this there would need to be regular monitoring of the Hub's successes. The monitoring would need to focus on the changes of industry in the areas such as plastic recyclate production, use of plastic recyclate into new products, creation of new companies, new jobs and the value of the plastic recyclate in the marketplace. In addition, it would be useful to monitor the views and opinions of all the affected groups of people to see if these had changed. This monitoring could take place on an annual basis and form the basis of the Hub's yearly report. Much of the information could be gathered and used as part of further SSM investigations in order to analyse the new situation in relation to the original situation, where further recommendations could then be made to further improve the situation. This information could be used to highlight successes for publication.

10.14 Benefits of the Hub

The Hub is a solution to a real life problem that is about to become a major issue in the UK and indeed the rest of Europe. It would help to bring together a wealth of knowledge and resource that would benefit every member of the Polymer Recycling System. The impact of the Hub would be to help industry achieve legislation targets for disposal of ELVs and to help society in general by creating a new industry with new jobs, reducing amounts of plastic entering landfill sites and saving the earth's raw materials that are used to manufacture new plastic.

The Hub would be operating in an open environment where representatives from various companies and other organisations could pool their resources, whilst largely remaining in their original geographical area. It would also mean that they would still be working within the organisation that they are representing, thus keeping a focus on company dynamics, political issues and needs.

The Hub itself would be a place where individuals could develop collectively, in an arena of openness and trust. They would develop their roles within the organisation as part of a team and would be responsible for themselves, their actions and the Hub itself. The Hub would be non-competitive by nature and any technologies created by the Hub could be used by the member organisations in the manner that they see fit. In this way, the profit making organisations work together to find generic solutions to issues in order to develop the infrastructure, without stifling any creativity within the individual companies to maximise their profits.

Once the infrastructure is fully operational and able to cope with the polymeric waste from ELVs, it is envisaged that systems would be further developed and improved, in order to maximise process effectiveness. It would be at the discretion of the Hub members as to which processes they would choose to collectively develop further.

The returns are both objective and subjective – there are positive financial implications for industry by using recycled plastic in their products: they would remove the plastic from the waste stream destined for landfill, and thus pay less landfill tax and keep pollution levels to a minimum.

It is important that each organisation that chooses to join the Hub does so because it sees the potential benefit for itself and is therefore committed to the idea. Thus, when electing a member of its organisation to become apart of the Hub, it would be more likely to choose wisely and carefully. Each organisation would need to understand that this would be a full time post and therefore there would be no conflict of interests as far as time is concerned[vi].
The elected member would be working full-time on the plastics recycling issue, representing the organisation that he or she comes from in order to solve recycling issues that would benefit the organisation, the Hub member organisations and society in general.

Membership of the Hub would be largely defined by which of the major stakeholders initially joined and who initiated financial backing. Therefore, with financial backing from the DTI and DETR, and the backing of groups such as the CARE Group, the BPF and large and influential organisations such as Shredder companies, other organisations would be likely to follow.

vi. [vi] A potential area for concern by critics. However the member organisations of the Hub would be held responsible for their role within the ELV disposal system. Therefore it is in their best interest to actively find solutions and help develop the needed infrastructure. Any deviance from this could be addressed by reminding the organisation of its legal obligation and its agreed role.

10.15 Drawbacks

The Hub is a long term initiative that sets out to achieve objective and subjective goals. When the goals are tangible – for example if the goal is set that 0.6 million tonnes of plastic needs to be removed from the UK waste stream, per year - it would be possible to measure this and to know whether it is being achieved, through monitoring plastics removal from ELVs at dismantler and shredders or by monitoring the amounts reprocessed by recyclers. It is potentially more difficult to measure the success rate of raising public awareness about recycling or the impact of education/media intervention etc.

However it is not impossible to measure subjective issues. The author has based her work on an investigation into this subject using SSM. It would therefore be possible for another SSM investigation to be carried out in the future to measure whether things have progressed and if so whether they have moved towards the goals that have been set out in this report.

Another possible barrier to the success of the Hub is if total commitment throughout the organisation is not achieved. For example, the Hub would need the commitment of the member organisations. It would also need the commitment of the individuals that make up the Hub. If there were not total alignment then it would be likely that people would not be working at maximum effort levels or indeed their effort could be mis-directed. If they were not doing this then they would be likely to compromise the effectiveness of the teams they work within and indeed the Hub itself. It would be one of the leader's tasks to coach the persons involved to overcome any issues that may arise in this area.

If there were split loyalties or the sponsoring company demanded that an individual Hub member act against the Hub's best interest (or indeed if the Hub asked the member to operate against his or her company's best interests), then the effectiveness of that individual and therefore the Hub would be compromised. Once again the author believes that there is a solution to every issue and the most important thing is for the leader and the person/people involved to understand exactly what the issue is and compromise where necessary.

10.16 Strategy to achieve each Hub issue

The individual strategies that would be used to implement each issue within the Hub have deliberately been left for the Hub members to develop in accordance with the Hoshin Kanri protocol. Far from the author avoiding the issues, this approach is deliberate to ensure that the Hub members develop the means themselves. This in turn would act to develop the team and use the collective knowledge of all the industries to promote best practice, rather than use autocratic methods to tell Hub members what to do.

The Polymer Recycling Hub concept has been created from the recommendations developed in the SSM investigation of the Polymer Recycling System as detailed in submission seven of the Engineering Doctorate Portfolio. This information was based on the collection of data from people within the Polymer Recycling System. Therefore the very people who are involved in the problem situation, will be affected by the imminent introduction of UK legislation and will be integral part of the system that can help them to achieve legislative targets – the Polymer Recycling Hub.

11 Innovation and the Demonstration of Application

This chapter describes the innovation that has emerged from the engineering doctoral research over the past six years and provides evidence of its demonstration, where possible.

11.1 Patent

In 1998 the Rover Group, then owned by BMW AG, filed a patent request for the invention entitled 'A Method of Moulding and a Moulding formed thereby'. The author developed an idea that she had together with 3 other people, which led to the patent request. Full details of this patent and the laboratory work carried out to achieve this are contained in submission two of the Engineering Doctorate Portfolio.

The patent is currently in the process of being raised, but has passed all of the selection criteria. The patent application number is 98178890.8[51]. Rover or BMW is not currently using the technology and it is unclear who will own the patent and or/use it in the future, due to the sale of Rover by BMW. Therefore it is not possible to demonstrate the use of this piece of innovation. However, clearly Rover/BMW decided that the invention had potential use, otherwise they would not have chosen to patent it.

11.2 Use of SSM with Mindmaps

In submissions six and seven of this Engineering Doctorate Portfolio, the author described the use of SSM and mindmaps together. Indeed the 'Rich Picture' was created using a variety of mindmaps.

In the author's research she was unable to find any documentary evidence to show that these had been used together before. This is therefore thought to be innovative and its demonstration of use can be seen in submission seven of the Engineering Doctorate Portfolio.

11.3 The Use of Hoshin Kanri to deploy SSM recommendations

Hoshin Kanri was chosen as a suitable technique to implement the recommendations from the SSM investigation into the Polymer Recycling System as it fits with the author's philosophy that she has developed throughout the Engineering Doctorate Portfolio.

In the author's research she was unable to find any documentary evidence to show that Hoshin Kanri has been used to deploy recommendations from SSM analysis before. This is therefore thought to be innovative and its demonstration of use can be seen in submission ten.

11.4 The Polymer Recycling Hub

The Polymer Recycling Hub, or the Hub for short, is a creation that offers an alternative solution to deploying policy level changes, taking the problem solving system of SSM one stage further, to provide a vision of how all the recommendations could be put into effect collectively. The implementation of legislation, directives and other government driven policies are often left to industry and/or local government, where they have to find solutions for themselves.

The Hub offers a new, independent method of solving the waste disposal issues, using the collective knowledge and resource of all those effected by the pending legislation. It has already received interest from car manufacturers, industrial organisations and the governmental department of trade and industry.

The author is not claiming this to be the one and only 'best' method of strategic implementation of the SSM recommendations. However, it does provide a cohesive model that provides a strategy for addressing the issues. The work also provides an implementation technique that allows the affected parties to devise the most appropriate method of execution for them, to effect change.

12 Application of Innovation

12.1 Rover sponsorship and rights to patent

Although Rover/BMW are not currently using the patent, they have clearly shown their belief in the potential of the innovative technique for moulding with shredder residue by fully backing the concept in patenting the idea.

12.2 Warwick University setting up polymer recycling centre and network

Part of the author's work throughout this Engineering Doctorate has aimed to bring different sectors within the Polymer Recycling System together and create an environment where they would work together to promote polymer recycling.

In 1998 as part of this initiative, the author proposed the creation of a polymer recycling network[52]. She therefore wrote an EPSRC proposal together with a Principal Research Fellow at the University of Warwick and the EPSRC accepted the proposal in the year 2000. This polymer recycling network is now in existence[53].

In addition to the above, the author promoted the idea of the university becoming a 'centre of excellence' for polymer recycling, which would locate it well in the market place, working with industry to help solve recycling issues[54]. This idea has also been adopted and the university now has a centre for plastics recycling within Warwick Manufacturing Group's Polymer Centre of Excellence[55]. This facility meets the concept of the Hub as it is developing its knowledge, network and capacity in plastics recycling. This could be combined with the strengths from the other associated parties in the polymer recycling system by the Hub to contribute to successes, particularly in areas of recycling knowledge, education, research project management and related funding issues.

Further information can be found in submission eleven of the Engineering Doctorate Portfolio.

12.3 Support from government, industry and associated organisations

The author is currently in the process of moving the Polymer Recycling Hub forward from concept to reality. To this end she has been lobbying support from a variety of groups from various sectors. Presentations have been made orally, and in written format and a business plan has been created. These can be seen in submission eleven of the Engineering Doctorate Portfolio.

The business plan has been presented to a DTI representative who has suggested that the proposal be put forward for joint DTI/DETR funding under the WRAP scheme (Waste Resources Action Programme) and also a European funding programme entitled EU-Life[28].

The CARE Group (Consortium of Automotive Recycling) is backing the concept of the Polymer Recycling Hub, having read the business plan and is now calling for its creation[56].

In addition, there is support from within the University of Warwick, the British Plastics Federation (BPF) and Jaguar Cars Limited[53].

The author believes that she will carry on gaining support for the Hub and that its implementation will occur after the procurement of sufficient funding. This is a long-term project that requires a high degree of work prior to reaching the implementation stage. Therefore, as an estimation, it is likely to take a further twelve months of lobbying and fund raising before the Hub starts to operate.

The author recognises that there is great value in this period, as the Hub is novel in its concept. It is likely that people will need time to understand its full potential and accept it.

12.4 The Author's Role as Project Manager for PRoVE

The author is currently Project Manager for a DTI funded project to develop generic specifications for recycled plastics. The project, which began in June 2001, is known as ProVE (Polymer Reprocessing Validation Exercise) and is a BPF/CARE group joint initiative. These specifications are not currently in existence and their creation will help to raise awareness, remove barriers and provide a vehicle for the author to continue lobbying and gain support for the Polymer Recycling Hub.

13 Further work

Much of the detail of the further work has been outlined in submissions eight and ten of the author's Engineering Doctorate Portfolio. Therefore this section provides a brief overview of the areas that need addressing.

It is of paramount importance that the author continues to lobby for support and apply for funding, initially from the DTI, DETR probably via the WRAP programme and European funds in order to begin creation of the Hub. Once funding has been secured, members of each of the organisations who are affected by the Polymer Recycling System would be brought together and preliminary coaching/training and culture building would be carried out.

The Hub would then develop its own strategy for developing the specific projects that would further the recycling of polymers in the UK. However, once the Hub is implemented, the facilitation and leadership of the Hub will need to be monitored to ensure the goals are achieved, in line with the principles of Hoshin Kanri. In this manner any modifications to the Hub implementation and day to day running could be made quickly, and as appropriate, to ensure achievement of the overall vision.

Overall, the author also believes that it would be appropriate to carry out another SSM analysis of the Polymer Recycling System after a period of 5 years to see whether there has been visible change. The findings of this research could be used by the Hub to modify where appropriate, its overall strategy.

14 Conclusion

This document has given an overview of the work that the author has undertaken as part of her Engineering Doctorate from 1996 to 2002 inclusive. This work has been jointly sponsored by the EPSRC and the Rover Group. The work has focused on the field of polymer recycling in the UK, with an automotive bias.

The report began by justifying the need for the project, highlighting the current situation that the automotive industry faces regarding the disposal of its end of life vehicles with the introduction of the EU Directive and the UK legislation that will follow.

It has been shown that the automotive industry will not currently be able to cope with the targets set by the EU Directive. Therefore, the automotive industry has to find methods of recycling the plastics from ELVs now, in order for it to create the systems capable of removing sufficient material to meet targets set out in the European Directive published in 2000.

The author's research has shown that the limiting factors for meeting waste disposal targets are not only technical but also business related. She found that the market for recycled plastics had associated supply and demand issues, as well as logistical and financial issues. The author also found that there were varying conceptions, beliefs and judgements associated with plastics recycling. This was true of many different interest groups, including design engineers, fellow researchers and most of the experts in the field. The author found that there was a spectrum of beliefs that were often negative in nature - particularly in relation to perceived public demands or the beliefs of other sectors of the automotive industry.

The author therefore undertook a study to understand further the polymer recycling industry, ensuring that the views of people from the various sectors within and affected by automotive polymer recycling were captured. This would aid understanding of current issues so that a new system, capable of reprocessing the high volume of polymeric waste from ELVs in the UK, could be developed.

The author began by embarking on a piece of research to find an appropriate problem solving tool, technique or methodology that would cope with the Polymer Recycling System. Soft Systems Methodology (SSM) was selected as the most appropriate methodology and this was used to explore further the Polymer Recycling System.

SSM provided the vehicle to create a variety of recommendations for the advancement of the Polymer Recycling System and in order to find an appropriate method of deployment the author investigated the concepts of Management by Objectives (MbO) and Hoshin Kanri. The author's investigation showed that Hoshin Kanri was an appropriate technique for implementing the recommendations to the Polymer Recycling System. In this way those operating within the system would define the detailed plan of action and therefore take responsibility for it. It follows that if they feel responsible for creating a plan then they are more likely to want its success than if they were told what to do in an abstract manner.

A model was created to guide the changes recommended from the SSM analysis which was given the name the "Polymer Recycling Hub" or the "Hub" for short. It focuses on the promotion of education and re-education of participants in the recycling system, the funding of new ventures, pilot schemes and research opportunities, to improve processes and develop new, as well as publicising and disseminating the information and provide training for those who require it.

The Hub was conceived as an independent body that would represent all the major players within the Polymer Recycling System. It would bring different sectors together, working in harmony to maximise their knowledge and to create an innovative, open and trusting environment.

This document has shown that further work will be needed for funding of the Hub to be established. It is expected that the UK Government (DTI/DETR via the WRAP programme) and the European Union will back the Hub. In addition to the financial support, the author also believes that industry and other sectors affected by the impending ELV legislation will have to be lobbied in the near future. This will give them an early chance to understand the concept of the Hub and give them the opportunity to be founder members.

In addition, the author has suggested that another SSM investigation be carried out, five years after the implementation of the Hub, to provide feedback about the changes to society with regard to the Polymer Recycling System. This information could be used to feedback into the Hub's vision and implementation process.

Overall, this piece of research, which has taken six years to complete, has provided evidence to show the current state of the Polymer Recycling System in the UK, with particular focus on the automotive waste stream. It has provided recommendations for changing the current situation, suggested an appropriate implementation technique and developed a model to bring these together. Finally the research has suggested further work is needed to realise and monitor its success.

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